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Environmental Assessment of a Commercial Boiler Fired with a Coal/Waste Plastic Mixture. Volume 1. Technical Results

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ENVIRONMENTAL ASSESSMENT OF A COMMERCIAL BOILER FIRED WITH A COAL/WASTE PLASTIC MIXTURE

Volume I
Technical Results

By

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U.S. ENVIORNMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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16. ABSTRACT The report gives results of comprehensive emissions testing and laboratory analyses of a stoker-fired commercial boiler firing a coal/waste plastic mixture. In one test, the unit fired its typical coal fuel; in the other, shredded waste polyethylene terephthalate (PET) beverage bottles were added to the coal to about 16% by weight in the mixed fuel. NOx, total unburned hydrocarbon, and solid particulate were relatively unchanged for the two tests, as was the emitted particle size distribution. SOx emissions decreased with the coal/PET fuel in keeping with its lowered sulfur content; average CO emissions were also decreased. Flue gas emissions of most trace elements were comparable for both tests, as were the trace element compositions of corresponding ash streams. However, lead emissions were significantly increased for the coal/PET fuel, reflecting an increased lead content of the mixed fuel. The cyclone hopper ash for the coal/PET test had consistently lower leachable trace element and anion content than for the coal fuel test. Total flue gas organic emissions were comparable for both tests, in the 1 mg/dscm range; although levels of several semivolatile priority pollutants were higher for the mixed fuel.

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SECTION 1

INTRODUCTION

This report describes and presents results of environmental assessment tests performed for the Air and Energy Engineering Research Laboratory/ Research Triangle Park (AEERL/RTP) of EPA under the Combustion Modification Environmental Assessment (CMEA) program, EPA Contract No. 68-02-3188. The CMEA started in 1976 with a 3-year study, the NO_x Control Technology Environmental Assessment (NO_x EA, EPA Contract No. 68-02-2160), having the following four objectives:

- Identify potential multimedia environmental effects of stationary combustion sources and combustion modification technology
- Develop and document control application guidelines to minimize these effects
- Identify stationary source and combustion modification R&D priorities
- Disseminate program results to intended users

During the first year of the NO_x EA, data for the environmental assessment were compiled and methodologies developed. Furthermore, priorities for the schedule and level of effort for the various source/fuel/control combinations were identified. This effort revealed major data gaps, particularly for noncriteria pollutants (organic emissions and trace elements) for virtually all combinations of stationary combustion sources and combustion modification techniques. Consequently, a series of seven environmental field test programs was undertaken to fill these data gaps. The results of these tests are documented in seven individual reports (Ref. 1-1 through 1-7) and in the NO_x EA final report summarizing the entire 3-year effort (Ref. 1-8).

The current CMEA program has, as major objectives, the continuation of multimedia environmental field tests initiated in the original NO_x EA program. These new tests, using standardized Level 1 sampling and analytical procedures (Ref. 1-9) are aimed at filling the remaining data gaps and addressing the following priority needs:

- Advanced NO_x controls
- Alternate fuels
- Secondary sources
- EPA program data needs
    - -- Residential oil combustion
    - -- Wood firing in residential, commercial, and industrial sources
    - -- High interest emissions determination (e.g., listed and candidate hazardous air pollutant species)
- Nonsteady-state operations

In recent years, some states have required deposits on beverage containers as a means of controlling litter and encouraging recycling and reclamation of natural resources. One posible means of reclaiming plastic beverage bottles is to use them as a source of fuel in an energy recovery operation. In one such project, the use of recycled polyethylene terephthalate (PET) bottles for fuel in a commercial boiler is being evaluated at a quarry and stone-cutting plant in Barre, Vermont.

The boiler being used is a coal-fired firetube unit with a underfeed stoker. For the tests the PET is mixed with the unit's typical coal fuel before being fired. Past efforts have indicated that PET is a clean, high-heating value waste with no apparent environmental problems associated with burning it.

The tests described in this report were conducted to quantify in detail the potential benefits and/or adverse environmental effects using reclaimed PET bottles as a fuel supplement. The data presented in this report quantify stack and collected flyash emissions and identify pollutants of potential concern using results from standardized sampling and analytical procedures (Ref. 1-9). Emissions from firing coal only in the boiler are compared to emissions from firing the coal/PET mixture at comparable boiler operating conditions.

Table 1-1 lists all sources tested in the CMEA effort, outlining the combustion modificaton controls implemented and the level of sampling and analysis performed in each case. Results of these test programs are discussed in separate reports.

TABLE 1-1. COMPLETED TESTS DURING THE CURRENT PROGRAM[a]

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Spark-ignited, natural-gas-fueled reciprocating internal combustion engine	Large bore, 6 cylinder, opposed piston, 186 kW (250 Bhp)/cyl, 900 rpm Model 38TDS8-1/8	-- Baseline (pre-NSPS) -- Increased air-fuel ratio aimed at meeting proposed NSPS of 700 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 5 -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Compression ignition, diesel-fueled reciprocating internal combustion engine	Large bore, 6 cylinder opposed piston, 261 kW (350 Bhp)/cyl, 900 rpm Model 38TDD8-1/8	-- Baseline (pre-NSPS) -- Fuel injection retard aimed at meeting proposed NSPS of 600 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Low-NO_x residential condensing heating system furnished by Karlsons Blueburner Systems Ltd. of Canada	Residential hot water heater equipped with M.A.N. low-NO_x burner, 0.55 ml/s (0.5 gal/hr) firing capacity, condensing flue gas	Low-NO_x burner design by M.A.N.	Furnace exhaust: -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Waste water	New test
Rocketdyne/EPA low-NO_x residential forced-warm-air furnace	Residential warm-air furnace with modified high-pressure burner and firebox, 0.83 ml/s (0.75 gal/hr) firing capacity	Low-NO_x burner design and integrated furnace system	Furnace exhaust: -- SASS -- Method 5 -- Controlled condensation -- Method 8 -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel	New test

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TABLE 1-1. (continued)

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Pulverized-coal-fired utility boiler, Conesville station	400-MW tangentially fired; new NSPS design aimed at meeting 301 ng/J NO_x emission standard	ESP inlet and outlet - one test	ESP inlet and outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2 Coal Bottom ash ESP ash	Exxon Research and Engineering (ER&E) conducting corrosion tests
Nova Scotia Technical College industrial boiler	1.14 kg/s steam (9,000 lb/hr)fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with limestone injection	Boiler outlet -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, CO, CO_2, NO_x Fuel	Envirocon performed particulate and sulfur emission tests
Adelphi University industrial boiler	1.89 kg/s steam (15,000 lb/hr) hot water firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with soda ash (Na_2CO_3) injection	Boiler outlet -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, CO_2, NO_x, SO_2, CO Fuel	Adelphi University
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-oil (COM)	-- Baseline test only with COM	Boiler outlet -- SASS -- Method 5 -- Controlled condensation -- N_2O grab sample -- Continuous O_2, CO_2, NO_x, CO, TUHC Fuel	PETC and General Electric (GE)

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TABLE 1-1. (continued)

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
TOSCO Refinery vertical crude oil heater	2.54 Ml/day (16,000 bbl/day) natural draft process heater burning oil/refinery gas	-- Baseline -- Staged combustion using air injection lances	Heater outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- N_2O grab sample -- Continuous O_2, NO_x, CO, CO_2, HC Fuel oil Refinery gas	KVB coordinating the staged combustion operation and continuous emission monitoring
Mohawk-Getty Oil industrial boiler	8.21 kg/s steam (65,000 lb/hr) watertube burning mixture of refinery gas and residual oil	-- Baseline -- Ammonia injection using the noncatalytic Thermal DeNO$_x$ process	Economizer outlet -- SASS -- Method 5, 17 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Ammonia emissions -- N_2O grab sample -- Continuous O_2, NO_x, CO, CO_2 Fuels (refinery gas and residual oil)	Mohawk-Getty Oil
Industrial boiler	2.52 kg/s steam (20,000 lb/hr) watertube burning wood waste	-- Baseline (dry wood) -- Green wood	Boiler outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, NO_x, CO Fuel Flyash	North Carolina Department of Natural Resources, EPA IERL-RTP
Industrial boiler	3.16 kg/s steam (29,000 lb/hr) firetube with refractory firebox burning wood waste	-- Baseline (dry wood)	Outlet of cyclone particulate collector -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, NO_x, CO Fuel Bottom ash	North Carolina Department of Natural Resources, EPA IERL-RTP

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TABLE 1-1. (continued)

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Enhanced oil recovery steam generator	15-MW (50 million Btu/hr) steam generator burning crude oil equipped with an MHI low-NO_x burner	-- Performance mapping -- Low-NO_x operation	Steamer outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1-C_6 HC) -- Continuous O_2, NO_x, CO, CO_2 -- N_2O grab sample Fuel	Getty Oil Company, CE-Natco
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a coal-water slurry (CWS)	-- Baseline test only with CWM	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1-C_6 HC) -- Continuous O_2, NO_x, CO, CO_2, TUHC -- N_2O grab sample Fuel Bottom ash Collector hopper ash	PETC and General Electric
Spark-ignited, natural gas-fired reciprocating internal combustion engine -- nonselective NO_x reduction catalyst	610-kW (818-hp) Waukesha rich-burn engine equipped with DuPont NSCR system	-- Low NO_x (with catalyst) -- 15-day emissions monitoring	Catalyst inlet and outlet -- SASS -- NH_3 -- HCN -- N_2O grab sample -- Continuous O_2, CO_2, NO_x TUHC Lube oil	Southern California Gas Company
Industrial boiler	180 kg/hr steam (400 lb/hr) stoker, fired with a mixture of coal and waste plastic beverage containers	-- Baseline (coal) -- Coal and plastic waste	Boiler outlet -- SASS -- VOST -- Method 5 -- Method 8 -- HCl -- Continuous O_2, NO_x, CO, CO_2, TUHC -- N_2O grab sample Fuel Bottom ash Cyclone ash	Vermont Agency of Environmental Conservation

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TABLE 1-1. (continued)

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Industrial boiler	7.6 kg/s steam (60,000 lb/hr) watertube retrofit for coal-water slurry (CWS) firing	-- Baseline test with CWS -- 30-day emissions monitoring	Boiler outlet -- SASS -- VOST -- Method 5 -- Method 8 -- Gas sample (C_1-C_6 HC) -- N_2O grab sample -- Continuous NO_x, CO, CO_2, O_2, TUHC, SO_2 Fuel	EPRI, DuPont
Enhanced oil recovery steam generator	15-MW (50 million Btu/hr) steam generator burning crude oil, equipped with the EPA/EER low-NO_x burner	-- Low NO_x (with burner) -- 30-day emissions monitoring	Steamer outlet -- SASS -- VOST -- Method 5 -- Method 8 -- Controlled condensation -- Anderson impactor -- Gas sample (C_1-C_6 HC) -- N_2O grab sample -- Continuous NO_x, CO, CO_2, O_2, SO_2 Fuel	Chevron U.S.A., EERC
Spark-ignited natural-gas-fired reciprocating internal combustion engine -- selective NO_x reduction catalyst	1,490-kW (2,000-hp) Ingersoll-Rand lean-burn engine equipped with Englehard SCR system	-- Low NO_x (with catalyst) -- 15-day emissions monitoring	Catalyst inlet and outlet -- SASS -- VOST -- NH_3 -- HCN -- N_2O grab sample -- Continuous O_2, CO_2, CO, NO, NO_x, NO_x+NH_3 Lube oil	Southern California Gas Company

[a] Acronyms used in the table: EERC, The Energy and Environmental Research Corporation; EPA IERL-RTP, The Environmental Protection Agency's Industrial Environmental Research Laboratory-Research Triangle Park; EPRI, The Electric Power Research Institute; HC, hydrocarbons; NSCR, nonselective catalytic reduction; NSPS, new source performance standard; SASS, source assessment sampling system; SCR, selective catalytic reduction; TUHC, total unburned hydrocarbon; VOST, volatile organic sampling train

REFERENCES FOR SECTION 1

1-1. Larkin, R. and E. B. Higginbotham, "Combustion Modification Controls for Stationary Gas Turbines: Volume II. Utility Unit Field Test," EPA-600/7-81-122b, NTIS PB82-226473, July 1981.

1-2. Higginbotham, E. B., "Combustion Modification Controls for Residential and Commecial Heating Systems: Volume II. Oil-fired Residential Furnace Field Test," EPA-600/7-81-123b, NTIS PB82-231176, July 1981.

1-3. Higginbotham, E. B. and P. M. Goldberg, "Combustion Modification NO_x Controls for Utility Boilers: Volume I. Tangential Coal-fired Unit Field Test," EPA-600/7-81-124a, NTIS PB82-227265, July 1981.

1-4. Sawyer, J. W. and E. B. Higginbotham, "Combustion Modification NO_x Controls for Utility Boilers: Volume II. Pulverized-coal Wall-fired Unit Field Test," EPA-600/7-81-124b, NTIS PB82-227273, July 1981.

1-5. Sawyer, J. W. and E. B. Higginbotham, "Combustion Modification NO_x Controls for Utility Boilers: Volume III. Residual-oil Wall-fired Unit Field Test," EPA-600/7-81-124c, NTIS PB82-227281, July 1981.

1-6. Goldberg, P. M. and E. B. Higginbotham, "Industrial Boiler Combustion Modification NO_x Controls: Volume II. Stoker Coal-fired Boiler Field Test -- Site A," EPA-600/7-81-126b, NTIS PB82-231085, July 1981.

1-7. Lips, H. I. and E. B. Higginbotham, "Industrial Boiler Combustion Modification NO_x Control: Volume III. Stoker Coal-fired Boiler Field Test -- Site B," EPA/600/7-81-126c, NTIS PB82-231093, July 1981.

1-8. Waterland, L. R., et al., "Environmental Assessment of Stationary Source NO_x Control Technologies -- Final Report," EPA-600/7-82-034, NTIS PB82-249350, May 1982.

1-9. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, NTIS PB293795, October 1978.

SECTION 2

SOURCE DESCRIPTION AND OPERATION AND TEST PROTOCOL

The tests were performed on a Federal Boiler coal-fired firetube commercial boiler equipped with a Will-Burt underfeed stoker located at a quarry and stone-cutting plant in Barre, Vermont. These tests were performed to evaluate any changes in discharge composition and mass throughput attendant with cofiring recycled plastic beverage bottles with the unit's coal fuel. One test was performed with the unit burning coal only, and another test was performed firing a mixture of coal and granulated polyethylene terephthalate (PET) beverage bottles.

2.1 BOILER DESCRIPTION

The unit tested was a Federal Boiler model FLR-1518 firetube boiler of the three pass design manufactured in 1982. The boiler is equipped with a Will-Burt underfeed stoker with a screw feeder and overfire air jet system. The coal feeder has nominal settings of 90, 135, and 180 kg/hr (200, 300, and 400 lb/hr). The boiler has a maximum working pressure of 100 kPa (15 psig) for steam or 200 kPa (30 psig) for hot water. A manual soot-blowing cycle is operated daily in the morning. The unit is used to provide steam for space heating at the stone-cutting plant of the quarry. Table 2-1 summarizes the design specifications for the unit.

TABLE 2-1. BOILER DESIGN SPECIFICATIONS

Boiler:	
Manufacturer	Federal Boiler Company
Model	FLR-1518
Design type	Three-pass firetube
Installation date	1982
Fireside heating surface, m^2 (ft^2)	76.8 (827)
Net rating:	
Heat input, MW (million Btu/hr)	1.9 (6.4)
Steam output, kg/s (lb/hr)	0.59 (4,640)
Working pressure	
Steam, kPa (psig)	100 (15)
Water, kPa (psig)	200 (30)
Stoker:	
Manufacturer	Will-Burt Company
Design type	Underfeed screw feeder with overfire jet air system
Cyclone particulate control:	
Manufacturer	Fisher-Klosterman
Model	XO 340-15
Gas flow, m^3/s (acfm)	1.2 (2,500)
Gas velocity, m/s (ft/s)	16 (50)
Inlet particle loading, g/m^3 (gr/acf)	0.34 (0.14)
Pressure drop, kPa (in. H_2O)	1.0 (4)

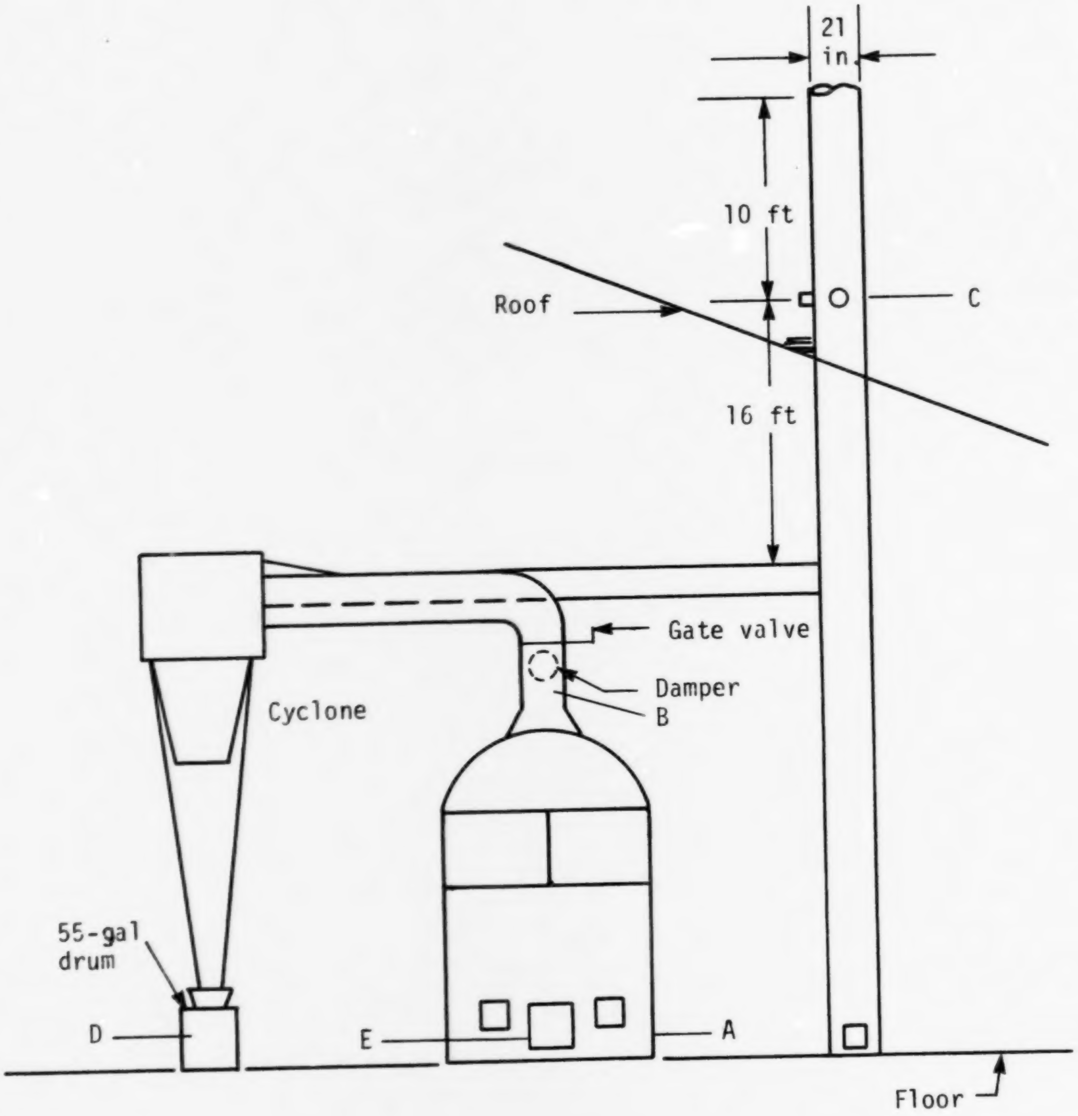
2.2 TEST PROTOCOL

Figure 2-1 shows a schematic of the boiler tested and indicates the sampling location employed in the tests. Table 2-2 summarizes the sampling methods used at each location. As noted in the table, the sampling matrix consisted of:

- Fuel grab sample
- Bottom ash grab sample
- Cyclone collector hopper ash grab sample
- Flue gas:
    - -- Continuous monitors for O_2, CO_2, CO, NO_x, and total unburned hydrocarbon (TUHC) both at the boiler exit and at the stack location
    - -- Volatile organic sampling train (VOST) sampling (test 2, coal/PET fuel only; equipment problems prevented obtaining a VOST run for test 1, coal fuel)
    - -- Source assessment sampling system (SASS) sampling
    - -- Combined EPA Method 5/8 sampling for particulate and sulfur oxides
    - -- HCl train sampling
    - -- Gas grab sampling for N_2O determination

All flue gas sampling was performed in the unit's stack, downstream of the cyclone collector, except for the continuous flue gas analyzers which were operated both at the stack and at the boiler exit. Details of the specific sampling protocols used are given in Appendix A.

As also indicated in Table 2-2, the analysis protocol for collected samples included:


21 in.
10 ft
Roof
C
16 ft
Gate valve
Damper
B
Cyclone
55-gal drum
D
E
A
Floor

A83-0279

Figure 2-1. Schematic of boiler and sampling locations.

TABLE 2-2. TEST MATRIX

Sample location	Type of sample/equipment	Analysis
A. Fuel hopper	Composite grab sample of coal, PET, and coal/PET mixture	Proximate, ultimate, and selected inorganic trace elements
B. Boiler outlet	Continuous monitors	NO_x, CO, CO_2, O_2, TUHC
C. Stack	Continuous monitors	NO_x, CO, CO_2, O_2, TUHC
	Volatile Organic Sampling Train (VOST)[a]	Volatile organic priority pollutants in accordance with EPA Method 624
	Source Assessment Sampling System (SASS)	Particulate size distribution, selected inorganic trace elements, total semi- and nonvolatile organics (boiling point >100°C), semivolatile organic priority pollutants in accordance with EPA Method 625, bioassay testing for mutagenicity and cytotoxicity
	High Volume Stack Sampler (HVSS)	Total particulate by EPA Method 5, SO_2 and SO_3 by EPA Method 8
	Gas grab sample	N_2O by laboratory GC/ECD
	HCl train[b]	HCl by wet chemistry
D. Cyclone (ash hopper)	Composite grab sample of flyash	Selected inorganic trace elements, leachable elements and anions, total nonvolatile organics, bioassay testing for mutagenicity and cytotoxicity
E. Boiler	Composite grab sample of bottom ash	Selected inorganic trace elements, leachable elements and anions, total nonvolatile organics, bioassay testing for mutagenicity and cytotoxicity

[a] Performed on test 2 only due to equipment problems.

[b] Impinger solutions for test 1 lost during transit, so only results for test 2 are reported.

- Performing proximate, ultimate, and heating value analyses of collected fuel samples
- Performing ultimate and heating value analyses of bottom ash and cyclone hopper ash samples
- Analyzing fuel, bottom ash, cyclone hopper ash, bottom ash aqueous leachate, cyclone hopper ash aqueous leachate, and SASS train samples for 73 trace elements using spark source mass spectrometry (SSMS) supplemented by atomic absorption spectrometry (AAS) and other methods
- Analyzing bottom ash and cyclone hopper ash aqueous leachates for selected anions by ion chromatography
- Analyzing VOST traps for the volatile organic priority pollutants
- Analyzing SASS train organic extract samples for total organic content in two boiling point ranges: 100°C to 300°C by total chromatographable organics (TCO) analysis, and >300°C by gravimetry (GRAV)
- Analyzing bottom ash and cyclone hopper ash organic extracts for total nonvolatile organic content by gravimetry
- Performing infrared spectrometry (IR) analysis of the GRAV residue of all organic extract samples
- Analyzing the SASS train sorbent module extract for the semivolatile organic priority pollutants, a set which includes many polynuclear aromatic hydrocarbon (PAH) compounds
- Performing liquid chromatographic (LC) separation of selected organic extract samples with subsequent TCO, GRAV, and IR analyses of eluted LC fractions

- Performing mutagenicity and cytotoxicity bioassay testing of SASS train, bottom ash, and cyclone hopper ash samples

This sampling and analysis matrix conforms to a modified and extended EPA Level 1 protocol (Ref. 2-1).

2.3 BOILER OPERATION

Two tests were performed in this program. In the first (test 1) the boiler was fired with coal fuel only. In the second (test 2) the boiler was fired with a coal/granulated PET waste mixture containing 16 percent PET by weight.

Table 2-3 summarizes the boiler operating conditions and the ultimate analysis of the fuel for each test. The steam load was measured by placing a totalizing flow meter on the boiler feed water. The firebox temperature was measured by inserting a probe through the door on the front of the unit. The fuel feed rate was determined by weighing the drums of fuel before and after each test. The conditions noted are those averaged over the period of the SASS tests.

Test 2 was run at approximately the same coal feedrate as test 1 (110 kg/hr); however about 20 kg/hr of PET waste was added to the fuel for this test (over the SASS sampling period). Consequently, heat input and boiler load were slightly higher for test 2. Also, near the end of test 2, some boiler load excursions were experienced at a plant shift change. These variations could affect the VOST and Method 5/8 results over and above the change in fuel composition.

Boiler efficiency, calculated using the ASME heat loss method, was about 79 percent for both tests. Table 2-4 summarizes the calculated heat losses as a percent of the total heat input for each test.

TABLE 2-3. SUMMARY OF BOILER OPERATION AND FUEL ANALYSES

	Test 1 (coal fuel)	Test 2 (coal/PET fuel)
Boiler operation (over the SASS sampling period)		
Steam load, kg/s (10^3 lb/hr)	0.38 (3.0)	0.42 (3.3)
Steam pressure, kPa (psig)	17 (2.5)	21 (3.0)
Feedwater inlet temperature, °C (°F)	12 (54)	13 (55)
Stack temperature, °C (°F)	146 (295)	165 (329)
Firebox temperature, °C (°F)	768 (1,415)	882 (1,620)
Fuel feedrate, kg/hr (lb/hr)	110 (240)	130 (285)
Excess air, percent	47	77
Boiler efficiency, percent	79.3	79.1
Fuel ultimate analysis (percent by weight as fired)		
Carbon	69.5	71.4
Hydrogen	5.2	5.5
Sulfur	1.0	0.6
Nitrogen	1.5	1.4
Oxygen[a]	11.4	11.7
Ash	8.5	6.8
Moisture	2.7	2.4
Chloride	0.2	0.2
Higher heating value, kJ/kg (Btu/lb)	31,212 (13,450)	31,270 (13,479)
PET, weight percent	0	16.4

[a] By difference.

TABLE 2-4. BOILER THERMAL EFFICIENCY

Heat loss efficiency (percent)	Test 1 (coal fuel)	Test 2 (coal/PET fuel)
Heat loss due to dry gas	8.3	7.8
Heat loss due to moisture in the fuel	0.1	0.1
Heat loss to water from combustion of H_2 in the fuel	4.0	4.3
Heat loss due to combustibles in the flyash	0.8	1.2
Heat loss due to radiation	5.5	5.5
Unmeasured losses	2.0	2.0
Total loss	20.7	20.9
Efficiency (percent)	79.3	79.1

REFERENCES FOR SECTION 2

2-1. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)", EPA 600/7-78-201, NTIS PB293795, October 1978.

SECTION 3

TEST RESULTS

The objective of this test program was to measure flue gas emissions and ash stream discharge composition from the boiler firing two fuels: the coal fuel typically burned, and the coal mixed with granulated recycled PET beverage bottles. The sampling and analysis matrix employed was discussed in Section 2. This section presents test results organized by pollutant grouping. Flue gas criteria pollutant and other gas phase emissions are discussed in Section 3.1, trace element emissions and ash stream inorganic composition are discussed in Section 3.2, and organic pollutant emissions and ash stream organic content are discussed in Section 3.3. Section 4 discusses the potential significance of the emissions and ash discharge compositions measured and presents results of the bioassay testing of samples collected.

3.1 CRITERIA POLLUTANT AND OTHER GAS PHASE SPECIES EMISSIONS

Table 3-1 summarizes the flue gas concentrations of the gaseous species measured by the continuous monitors along with particulate, sulfur oxides, N_2O, and HCl (for test 2; test 1 HCl train samples were destroyed during transport to the laboratory for analysis). As noted in the table, the continuous emission analyzers sampled combustion gas at both the boiler outlet and in the stack downstream of a flue duct damper and a cyclone particulate collector (at the location where the extractive sampling trains were operated). The data in Table 3-1 clearly show that significant air inleakage

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TABLE 3-1. CRITERIA POLLUTANT AND OTHER GAS SPECIES EMISSIONS

Pollutant	Test 1 (coal fuel) Range	Test 1 (coal fuel) Average	Test 2 (coal/PET fuel) Range	Test 2 (coal/PET fuel) Average
Boiler outlet (as measured emissions)				
O_2, percent dry	6.0 to 9.2	7.0	2.4 to 7.8	5.2
CO_2, percent dry	9.7 to 13.4	12.0	8.7 to 15.8	12.9
NO_x, ppm dry	185 to 220	200	115 to 205	182
CO, ppm dry	110 to 290	174	15 to 260	130
TUHC, ppm dry	<1 to 19	12	1 to 45	4
Stack outlet (as measured emissions)				
O_2, percent dry	11.0 to 13.0	12.2	7.3 to 10.0	8.8
CO_2, percent dry	6.3 to 8.6	7.1	4.9 to 9.9	7.5
NO_x, ppm dry	110 to 160	140	90 to 195	145
CO, ppm dry	50 to 120	90	25 to 90	55
TUHC, ppm dry	<1	<1	1 to 4	2
SO_2, ppm dry		455		434
SO_3, ppm dry		2.1		1.7
N_2O, ppm dry		28		61
HCl, ppm dry		--[a]		228
Particulate, mg/dscm				
Method 5		53.9		69.3
SASS		32.6		--[b]

	Test 1 ppm[c]	Test 1 ng/J[d]	Test 1 lb/million Btu[d]	Test 2 ppm[c]	Test 2 ng/J[d]	Test 2 lb/million Btu[d]
Stack outlet (corrected emissions)						
NO_x (as NO_2)	286	176	0.410	214	165	0.384
CO	184	69	0.16	81	38	0.089
TUHC (as CH_4)	<2	<0.4	<0.001	3	0.8	0.002
SO_2	930	800	1.9	640	690	1.6
SO_3	4.4	4.6	0.011	2.5	3.4	0.0078
N_2O	57	34	0.078	90	66	0.15
HCl	--[a]	--	--	336	206	0.479
Solid particulate						
Method 5		35.4	0.082		41.2	0.096
SASS		21.4	0.050		--[b]	--

[a] HCl train sample from test 1 destroyed during transit.

[b] Total SASS particulate emissions for test 2 could not be calculated; 1 μm cyclone particulate catch destroyed during transit.

[c] Corrected to 3 percent O_2, dry.

[d] Heat input basis.

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occurred between those two locations. Stack O_2 levels were higher than boiler outlet O_2 levels and stack CO_2, CO, NO_x, and TUHC levels were significantly lower than boiler outlet levels.

The data in Table 3-1 show that the addition of PET to the coal fuel did not radically alter emissions of NO_x, TUHC, and particulate. CO emissions were decreased by roughly a factor of two for the coal/PET fuel probably due to higher levels of excess air. Particulate emissions increased about 30 percent with the coal/PET fuel, though for both tests emissions were below 43 ng/J (0.1 lb/million Btu) heat input. Particulate emissions measured using the single point sampling SASS train were 40 percent lower than those measured using the stack traversing, isokinetic Method 5 reference method for test 1. (Test 2 SASS particulate emissions could not be calculated because one of the four SASS particulate size fraction samples, the 1-µm cyclone particulate catch, was destroyed while being transported to the laboratory for analysis.) Discrepencies between SASS and Method 5 are commonly of this order, although closer agreement is obtained more frequently than not. The Method 5 result is the more accurate.

Sulfur oxides (SO_2 and SO_3) emissions were decreased in test 2 on both a flue gas concentration (ppm) and per unit heat input (ng/J) basis. However, mass emissions (ng/s) in the flue gas were relatively constant for both tests, as shown in Table 3-2. This is because the coal firing rate in both tests was comparable. Table 3-2 indicates that flue gas sulfur oxide emissions accounted for between 96 (test 1) and 98 (test 2) percent of the output sulfur from the boiler. SO_3 accounted for about 0.5 percent of the total flue gas sulfur oxides. This is at the low end of the range typical for coal combustion sources. Sulfur mass balance closure was fair for the

TABLE 3-2. SULFUR MASS BALANCE

	Test 1 (coal fuel)	Test 2 (coal/PET fuel)
Input sulfur		
Sulfur in fuel		
Percent	1.0	0.66
mg/s[a]	303	238
Total input, mg/s	304	238
Output sulfur		
Flue gas		
SO_2, ng/J	797	687
mg/s[a]	376	388
SO_3, ng/J	4.6	3.4
mg/s[a]	2	2
Bottom ash		
Percent S	0.24	0.18
mg/s[a]	9	4
Cyclone ash		
Percent S	5.0	3.0
mg/s[a]	6	2
Total output, mg/s[b]	393	396
Balance out/in	1.30	1.66

[a] As sulfur
[b] Sulfur output in flue gas particulate negligible

tests; output sulfur totaled 130 percent of input for test 1 and 166 percent for test 2. The poorer result for test 2 is most likely due to difficulties in obtaining a representative sample of the mixed fuel for ultimate analysis. The apparent decrease in mixed fuel (coal/PET) sulfur content is more than that accountable for by the addition of sulfur-free PET to the coal.

Table 3-1 shows that HCl emissions measured 336 ppm (corrected to 3 percent O_2) in test 2. This is more than can be accounted for by the chlorine content of the coal/PET fuel fired, as shown in Table 3-3. Mass balance closure for chlorine in this test was relatively poor. Output chlorine (almost exclusively flue gas HCl as measured by the HCl train) was apparently 285 percent of that accounted for by the fuel.

Table 3-4 summarizes results of the ultimate analyses of the bottom ash and cyclone hopper ash samples collected. The combustibles content of the ash (chiefly carbon) was higher in both ash fractions for the coal/PET test (test 2), as reflected in the gross heating value of the samples. Similarly, the carbon content of the flue gas particulate was higher for test 2 (21.1 percent) than for test 1 (14.5 percent). However, total combustible losses in refuse and flyash were small compared to dry gas and flue gas moisture heat loss so that boiler efficiency was not overly affected by these (see Section 2.3).

Table 3-5 summarizes the particle size distribution data obtained from the different SASS train particle size fraction samples. The columns labeled "actual data" refered to actual measurements made and reflect the fact that no weight for the 1 μm SASS cyclone (the 1 to 3 μm size range) was obtained. However, the data in these columns show that the relative distribution of particulate among the >10 μm, 3 to 10 μm, and <1 μm size fraction was quite

TABLE 3-3. CHLORINE MASS BALANCE

	Test 2 (coal/PET)
Input chlorine	
Chlorine in fuel	
Percent Cl	0.23
mg/s[a]	83.1
Total input, mg/s	83.1
Output chlorine[a]	
Flue gas[a]	
HCl, ng/J	206
mg/s[b]	233
Bottom ash	
Percent Cl	0.08
mg/s[b]	1.9
Cyclone ash	
Percent Cl	0.26
mg/s[b]	0.2
Total ouptut, mg/s	237
Balance out/in	2.85

[a] As measured by the HCl train

[b] As Cl

TABLE 3-4. ASH DISCHARGE ULTIMATE ANALYSES
(percent by weight, as received)

	Bottom ash		Cyclone hopper ash	
Component	Test 1	Test 2	Test 1[a]	Test 2
Carbon	16.67	21.17	28.17	32.26
Hydrogen	0.14	0.17	1.13	0.88
Nitrogen	0.20	0.35	0.94	1.15
Sulfur	0.24	0.18	4.15	2.78
Oxygen[b]	1.08	0.54	11.25	9.69
Chlorine	0.05	0.08	0.18	0.25
Ash	81.47	77.37	45.33	49.00
Moisture	0.15	0.14	8.85	3.99
Gross heating value, kJ/kg (Btu/lb)	1,390 (600)	3,710 (1,600)	10,200 (4,395)	11,900 (5,130)

[a] Average of duplicate determinations

[b] By difference

TABLE 3-5. EMITTED PARTICLE SIZE DISTRIBUTION FROM SASS TRAIN CATCHES

	Actual data				Inferred data[a]			
	Test 1		Test 2		Test 1		Test 2	
Size fraction	Size fraction emission rate (mg/dscm)	Percent of 10 μm + 1 μm + filter catch	Size fraction emission rate (mg/dscm)	Percent of 10 μm + 1 μm + filter catch	Size fraction emission rate (mg/dscm)	Percent of of total	Size fraction emission rate (mg/dscm)	Inferred percent of of total
>10 μm	9.5	32	10.7	26	9.5	29	10.7	23
3 to 10 μm	7.9	26	12.7	30	7.9	24	12.7	28
1 to 3 μm	2.9	--	--	--	2.9	9	4.2[a]	9
<1 μm	12.3	42	18.6	44	12.3	38	18.6	40
Total	32.6	--	--	--	326	100	46.2	100

[a] Inferred assuming 1 to 3 μm size fraction for test 2 accounted for 9 percent of the total SASS train particulate catch

similar for both tests. The 1 to 3 μm size fraction for test 1 accounted for 9 percent of the total particulate for this test. If it is assumed that this fraction also accounts for the same percentage in test 2, the results summarized in the columns labeled "inferred data" are obtained. If this is the case, then the data suggest that the size distribution of emitted particulate was unaffected by the addition of PET to the coal fired.

Table 3-1 noted that N_2O emissions were measured at 57 (test 1) to 90 (test 2) ppm (corrected to 3 percent O_2). These levels correspond to 20 to 40 percent of the measured NO_x ($NO + NO_2$) levels for each test. This range is comparable to that seen in similar data obtained in recent tests in this project. Figure 3-1 summarizes all the data obtained in the combustion source tests performed in this project, noting the two points obtained in this test program. The least squares curve fit noted in the figure suggests that N_2O emissions from these external combustion sources are generally 20 percent of the corresponding NO_x emission level. Data from this test program, especially for test 1, support this approximate relationship.

3.2 TRACE ELEMENT AND LEACHABLE ANION DISCHARGE CONCENTRATIONS

The boiler flue gas SASS train samples, the coal and coal/PET fuels, the bottom ash, and the cyclone hopper ash were analyzed for 73 trace elements using spark source mass spectrography (SSMS) supplemented by atomic absorption (AAS) for mercury, antimony, arsenic, and selected major components of samples present at levels greater than the quantitation limit of SSMS. Specific ion electrode, colorimetric, turbidimetric, or X-ray fluorescence spectrometry techniques were used for other major components in samples as appropriate.

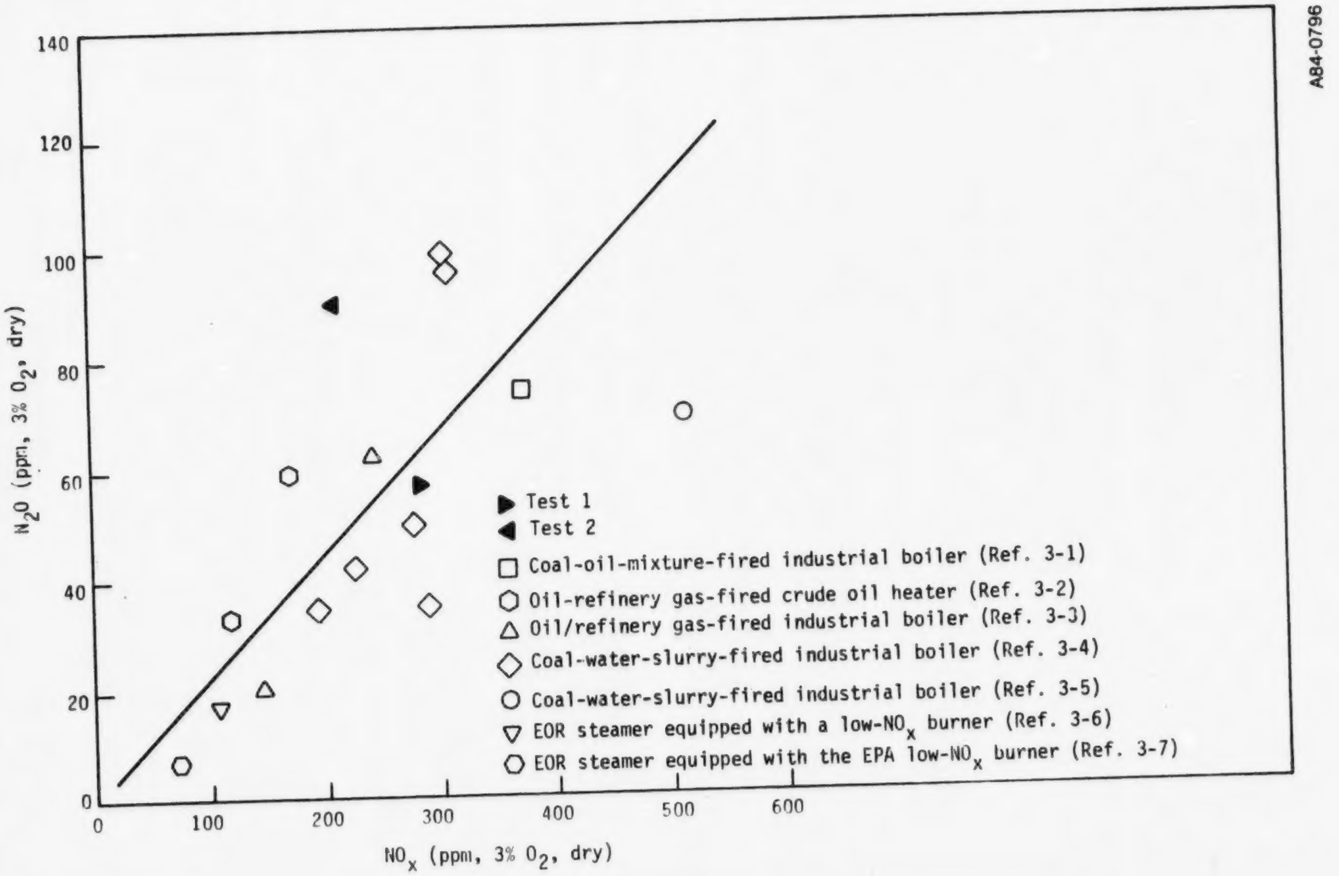

Figure 3-1. N_2O versus NO_x emissions for external combustion sources.

In addition, aqueous leachates of the bottom ash and cyclone hopper ash samples were prepared by extracting a given weight of ash into a volume of deionized water equal to four times the ash sample weight in accordance with EPA Level 1 protocol (Ref. 3-8). These leachates were analyzed for 73 trace elements by procedures noted above, and for 7 leachable anions using ion chromatography.

Section 3.2.1 discusses the SASS train solid ash sample trace element content results; ash sample leachate analysis results are discussed in Section 3.2.2.

3.2.1 Flue Gas and Solid Ash Trace Element Analysis Results

Complete sample trace element concentration data, calculated emission concentrations, and calculated discharge stream trace element flowrates are given in Appendix B. Table 3-6 summarizes the analysis results for the fuel, bottom ash, cyclone hopper ash, and SASS particulate for test 1 (coal fuel); Table 3-7 presents an analogous summary for test 2 (coal/PET fuel).

The data in Table 3-6 show that, for test 1, the trace element compositions of the boiler bottom ash and the cyclone hopper ash were generally similar (within a factor of 3 or so), as were the compositions of the two size fractions of flue gas particulate. The element concentrations in the particulate were consistently higher than those of the boiler and hopper ashes, especially for the more volatile elements (e.g., arsenic, antimony, beryllium, cadmium, lead, etc.). This is consistent with the partitioning tendencies of these elements noted in past combustion source tests.

TABLE 3-6. FUEL AND ASH STREAM TRACE ELEMENT ANALYSIS RESULTS: TEST 1

	Concentration (μg/g)				
				Flue gas particulate	
Element[a]	Fuel[b]	Bottom ash	Cyclone hopper ash	10 + 3 μm	1 μm + filter
Aluminum	11,900	129,000	56,200	75,800	53,900
Antimony	<1	4.0	6.0	150	51
Arsenic	11	4.0	52	490	550
Barium	100	350	130	1,900	940
Beryllium	9.0	22	7.0	31	29
Bismuth	<0.2	<0.1	0.4	6.0	20
Boron	30	31	110	230	>1,000
Bromine	21	4.0	49	220	250
Cadmium	1.0	0.4	0.4	14	77
Calcium	1,930	11,900	6,700	13,200	111,000
Cerium	18	22	4.0	150	61
Cesium	0.5	2.0	0.4	11	4.0
Chlorine	2,000	98	250	850	470
Chromium	120	50	510	40	150
Cobalt	8.0	22	6.0	64	100
Copper	14	18	34	722	440
Dysprosium	<0.2	3.0	1.0	9.0	3.0
Erbium	<0.2	2.0	0.5	4.0	1.0
Europium	0.3	2.0	0.4	3.0	3.0
Fluorine	830	<100	260	880	>1,000
Gadolinium	0.7	3.0	0.9	6.0	4.0
Gallium	16	1.0	19	830	350
Germanium	1.0	1.0	4.0	56	39
Hafnium	<0.2	3.0	0.3	2.0	1.0
Holmium	<0.2	2.0	0.7	6.0	2.0
Iodine	1.0	2.0	3.0	29	6.0
Iron	3,400	47,500	95,200	108,000	82,100
Lanthanum	24	30	6.0	87	61
Lead	3.0	9.0	14	460	600
Lithium	74	120	79	950	>370
Lutetium	<0.2	0.3	<0.1	0.4	0.3
Magnesium	480	4,600	1,500	4,300	15,400
Manganese	8.0	13	11	900	67
Mercury	0.09	<0.01	0.78	5.0	0.06
Molybdenum	27	6.0	8.0	84	65

(continued)

[a] Gold, iridium, osmium, palladium, platinum, rhenium, rhodium, and ruthenium were also analyzed for but were present at less than the method detection limit (0.1 to 0.2 μg/s) in all samples

[b] Fuel was 8.5 percent ash

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TABLE 3-6. (continued)

	Concentration (μg/g)				
				Flue gas particulate	
Element[a]	Fuel[b]	Bottom ash	Cyclone hopper ash	10 + 3 μm	1 μm + filter
Neodymium	7.0	14	3.0	28	32
Nickel	2	160	79	830	210
Niobium	12	9.0	4.0	48	14
Phosphorus	100	740	2,700	16,700	122,000
Potassium	1,160	12,400	5,100	11,700	43,900
Praseodymium	3.0	7.0	1.0	24	14
Rubidium	5.0	8.0	2.0	72	15
Samarium	1.0	7.0	3.0	17	12
Scandium	35	30	26	73	10
Selenium	130	13	170	<10	400
Silicon	18,700	212,000	82,000	128,000	>1,000
Silver	<0.2	0.5	0.5	35	12
Sodium	520	5,600	2,600	4,500	33,700
Strontium	110	210	90	1,200	420
Sulfur	10,000	320	40,500	15,900	33,100
Tantalum	<0.2	0.9	0.4	2.0	2.0
Tellurium	<0.2	<0.2	0.4	3.0	2.0
Terbium	0.2	0.8	0.2	2.0	1.0
Thallium	<0.2	1.0	2.0	40	31
Thorium	5.0	14	2.0	20	25
Thulium	<0.2	0.2	0.2	0.8	0.4
Tin	0.5	0.8	1.0	43	30
Titanium	540	6,800	3,500	6,800	5,100
Tungsten	<0.2	1.0	0.5	8.0	12
Uranium	2.0	9.0	2.0	9.0	62
Vanadium	40	44	85	940	66
Ytterbium	<0.2	1.0	0.5	3.0	2.0
Yttrium	10	11	5.0	82	58
Zinc	53	11	37	610	860
Zirconium	31	34	8.0	240	68

[a] Gold, iridium, osmium, palladium, platinum, rhenium, rhodium, and ruthenium were also analyzed for but were present at less than the method detection limit (0.1 to 0.2 μg/s) in all samples

[b] Fuel was 8.5 percent ash

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TABLE 3-7. FUEL AND ASH STREAM TRACE ELEMENT ANALYSIS RESULTS: TEST 2

	Concentration (μg/g)				
				Flue gas particulate	
Element[a]	Fuel[b]	Bottom ash	Cyclone hopper ash	10 + 3 μm	1 μm + filter
Aluminum	15,600	164,000	66,600	90,300	13,000
Antimony	24	15	26	680	<100
Arsenic	3.0	7.0	70	810	1,300
Barium	41	985	360	830	53
Beryllium	0.8	24	10	43	25
Bismuth	2.0	<0.1	1.0	20	86
Boron	14	130	840	<80	>1,000
Bromine	10	5.0	77	220	240
Cadmium	2.0	4.0	8.0	67	700
Calcium	930	25,900	22,700	13,700	2,500
Cerium	4.0	22	42	75	3.0
Cesium	0.9	5.0	2.0	4.0	16
Chlorine	2,300	36	250	4,200	300
Chromium	43	220	68	1,400	200
Cobalt	9.0	110	10	74	240
Copper	27	48	45	650	180
Dysprosium	<0.1	8.0	5.0	9.0	<0.5
Erbium	<0.1	4.0	2.0	4.0	<0.2
Europium	<0.1	4.0	0.8	3.0	0.3
Fluorine	71	250	380	340	310
Gadolinium	<0.1	8.0	2.0	8.0	1.0
Gallium	5.0	63	22	290	>1,000
Germanium	<0.1	4.0	8.0	44	330
Hafnium	<0.1	5.0	<0.7	3.0	<0.1
Holmium	<0.1	5.0	3.0	6.0	<0.3
Iodine	0.9	0.7	8.0	12	7.0
Iron	3,800	38,600	113,000	112,000	39,400
Lanthanum	6.0	66	35	90	3.0
Lead	28	52	70	890	46,900
Lithium	5.0	54	380	200	>310
Lutetium	<0.2	0.9	0.2	10	<0.1
Magnesium	370	4,700	4,300	4,000	1,000
Manganese	17	72	27	200	400
Mercury	0.2	<0.01	1.15	6.0	0.08
Molybdenum	17	16	20	140	170

(continued)

[a] Gold, iridium, osmium, palladium, platinum, rhenium, rhodium, and ruthenium were also analyzed for but were present at less than the method detection limit (0.1 to 0.2 μg/s) in all samples

[b] Fuel was 6.8 percent ash

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TABLE 3-7. (continued)

	Concentration (μg/g)				
				Flue gas particulate	
Element[a]	Fuel[b]	Bottom ash	Cyclone hopper ash	10 + 3 μm	1 μm + filter
Neodymium	4.0	32	15	48	4.0
Nickel	340	150	39	250	250
Niobium	2.0	15	9.0	29	2.0
Phosphorus	170	1,000	3,300	17,100	39,300
Potassium	910	11,400	6,400	12,200	28,600
Praseodymium	2.0	10	7.0	22	1.0
Rubidium	2.0	25	5.0	22	96
Samarium	1.0	15	4.0	20	2.0
Scandium	9.0	41	8.0	50	13
Selenium	4.0	17	130	400	300
Silicon	13,700	213,000	98,400	150,000	38,900
Silver	<0.1	0.6	1.0	12	19
Sodium	370	5,200	2,700	5,200	5,700
Strontium	24	510	170	420	71
Sulfur	6,600	5,400	28,100	30,600	25,800
Tantalum	3.0	5.0	1.0	2.0	4.0
Tellurium	<0.1	0.3	0.4	2.0	8.0
Terbium	<0.1	3.0	0.6	1.0	0.2
Thallium	<0.1	4.0	14	31	96
Thorium	4.0	31	11	25	2.0
Thulium	<0.1	1.0	0.4	0.4	<0.1
Tin	0.9	2.0	5.0	30	250
Titanium	480	7,400	4,500	8,300	110
Tungsten	<0.1	4.0	2.0	12	33
Uranium	2.0	22	12	62	78
Vanadium	11	24	45	66	170
Ytterbium	<0.1	7.0	1.0	2.0	<0.1
Yttrium	4.0	62	11	58	7.0
Zinc	10	23	88	680	1,000
Zirconium	8.0	92	19	68	6.0

[a] Gold, iridium, osmium, palladium, platinum, rhenium, rhodium, and ruthenium were also analyzed for but were present at less than the method detection limit (0.1 to 0.2 μg/s) in all samples

[b] Fuel was 6.8 percent ash

Table 3-7 suggests similar conclusions for test 2; however, for this test the difference between the flue gas particulate composition and that of the bottom and hopper ashes is less pronounced and less consistent.

Comparing the data in Tables 3-6 and 3-7 shows that the trace element composition of corresponding samples between the two tests were generally comparable (again with a factor of 3) with the notable exception of lead, which is discussed below. On a mass flow basis, the total ash in test 2 exceeded test 1 by 40 percent. The ratio of cyclone to bottom ash was about the same for the two tests.

Table 3-8 summarizes the total flue gas emission concentration (appropriated weighted sums of all SASS train samples analyzed: particulate fractions, sorbent resin, and impinger solutions) of the trace elements analyzed for both tests. For test 2, the estimated emission rate of 1 to 3 μm particulate as discussed in Section 3.1 (Table 3-5) was used together with the assumption that the composition of the total fine particulate catch (<3 μm) was the same as that of the <1μm particulate sample analyzed for this test.

The data in the table show that flue gas emission concentrations for most elements were comparable for both tests. Notable exceptions however, were chromium, iron, lead, nickel, and sodium, and to a lesser extent cobalt and molybdenum. The SASS train sample accounting for the largest fraction of all these elements, except lead, for test 2 was the first impinger solution. (Concentrations of these elements in the first impinger solution from test 1 were relatively low and had little contribution to the total SASS train emission concentrations). In fact concentrations of chlorine, fluorine, and sulfur were quite high in this sample as well.

TABLE 3-8. TRACE ELEMENT EMISSIONS IN THE FLUE GAS

	Test 1 (coal fuel)		Test 2[a] (coal/PET fuel)	
Element	(μg/dscm)	(pg/J)	(μg/dscm)	(pg/J)
Aluminum	2,150	1,380	2,450	1,430
Antimony	3.5	2.2	18	10
Arsenic	17	11	49	29
Barium	56	36	21	12
Beryllium	0.98	0.63	1.6	0.93
Bismuth	0.41	0.26	2.5	1.4
Boron	>20	>12	>24	>14
Bromine	8.6	5.5	16	94
Cadmium	2.5	1.6	18	10
Calcium	1,930	1,240	485	284
Cerium	3.5	2.3	1.8	1.1
Cesium	1.2	0.77	1.9	1.1
Chromium	10	6.5	5,170	3,030
Cobalt	3.0	1.9	41	24
Copper	32	20	35	21
Dysprosium	0.20	0.13	0.22	0.13
Erbium	0.085	0.054	0.098	0.057
Europium	0.098	0.063	0.077	0.045
Gadolinium	0.16	0.11	0.21	0.12
Gallium	21	13	>31	>18
Germanium	1.8	1.2	8.8	5.1
Hafnium	0.050	0.032	0.070	0.041
Holmium	0.13	0.087	<5.5	<3.2
Iron	3,180	2,050	27,600	16,200
Lanthanum	2.4	1.6	2.2	1.3
Lead	30	20	1,100	646
Lithium	>26	>17	>14	>8.1
Lutetium	0.011	0.0074	0.023	0.014
Magnesium	467	300	208	122
Manganese	19	12	120	70

(continued)

[a] Emission concentrations for test 2 estimated based on assumed emission rate of 1 to 3 μm particulate (see Table 3-5) and assuming that total <3 μm particulate compositions is that given by the <1 μm particulate sample analysis result

TABLE 3-8. (continued)

Element	Test 1 (coal fuel) (µg/dscm)	Test 1 (coal fuel) (pg/J)	Test 2[a] (coal/PET fuel) (µg/dscm)	Test 2[a] (coal/PET fuel) (pg/J)
Mercury	1.4	0.87	2.2	1.3
Molybdenum	3.9	2.5	28	16
Neodymium	0.97	0.63	1.2	0.71
Nickel	27	17	3,810	2,230
Niobium	1.0	0.67	0.83	0.49
Phosphorus	2,150	1,390	1,350	792
Potassium	914	589	966	566
Praseodymium	0.63	0.40	0.54	0.32
Rubidium	2.0	1.3	3.1	1.8
Samarium	0.48	0.31	0.51	0.30
Scandium	1.6	1.0	1.5	0.89
Selenium	10	6.8	41	24
Silicon	<2,360	>1,520	5,120	3,000
Silver	2.6	1.7	1.8	1.0
Sodium	652	420	107,000	62,800
Strontium	28	18	18	11
Tantalum	0.065	0.042	0.19	0.11
Tellurium	0.32	0.21	0.48	0.28
Terbium	0.050	0.032	0.051	0.030
Thallium	2.7	1.8	3.2	1.9
Thorium	0.73	0.47	0.23	0.14
Thulium	0.020	0.013	0.019	0.011
Tin	3.8	2.4	6.6	3.9
Titanium	220	140	220	130
Tungsten	0.32	0.21	1.2	0.71
Uranium	1.1	0.71	2.0	1.2
Vanadium	18	11	12	7.3
Ytterbium	0.082	0.053	0.23	0.14
Yttrium	2.3	1.5	1.7	0.97
Zinc	73	47	52	31
Zirconium	5.3	3.4	1.5	0.9

[a] Emission concentrations for test 2 estimated based on assumed emission rate of 1 to 3 µm particulate (see Table 3-5) and assuming that total <3 µm particulate compositions is that given by the <1 µm particulate sample analysis result

Several conjectures could be forwarded to account for these changes. Further measurement and evaluation would be needed to resolve the discrepancy, however.

In the case of lead, the increased emissions for test 2 can be traced to a significantly higher lead content of the filter particulate (which is not surprising since lead is relatively volatile and therefore tends to concentrate in fine particulate fractions). Comparing the lead levels noted in Table 3-7 with those in Table 3-6 shows that the coal/PET fuel had a factor of 10 higher lead content. Appendix B, which tabulates all sample trace element analysis data, confirms that the waste PET is the source of the lead; the lead content of the waste PET was 32 ppm compared to a 3 ppm level in the coal. It is not clear which aspect of the PET is the source of the lead. All ash samples, except the coarse (>3 µm) particulate had higher lead content for test 2 than for test 1. The fine particulate for test 2, as noted above, had significantly higher lead content than for test 1.

Unfortunately, the significantly increased lead emission level apparent in test 2 is based on the assumptions noted above. These are that the 1 to 3 µm SASS particulate emission rate was estimated based on the assumption (supported by the data, though) that the particle size distributions for the two tests were similar, and that the composition of the 1 to 3 µm particulate was the same as that of the less than 1 µm (SASS filter) particulate. This last assumption is most critical in light of the extreme apparent partitioning tendencies of lead (the much higher <1 µm particulate concentration compared to the >3 µm particulate). However, under these assumptions, the mass balance closure for lead for both tests is comparable, as noted in Appendix B. The ratio of total lead output to fuel input was

62 percent for test 1 and 86 percent for test 2 under the assumptions made. This suggests that the assumptions made were reasonable and conclusions based on them defensible.

3.2.2 Ash Sample Aqueous Leachate Analysis Results

As noted above, aqueous leachates of the bottom ash and cyclone hopper ash samples were prepared by extracting a given weight of ash into a volume of deionized water equal to four times the ash sample weight in accordance with Level 1 guidelines (Ref. 3-8). The leachates were analyzed for trace elements and selected anions. Analysis results are summarized in Table 3-9.

The data in Table 3-9 show that the cyclone hopper ash leachate had significantly higher trace element and leachable anion concentrations than the bottom ash leachate for both tests. The composition of the bottom ash for both tests were comparable, although the test 2 leachate had slightly higher concentrations for most elements. In contrast, the test 2 cyclone hopper ash leachate had consistantly lower trace element concentrations than the test 1 leachate.

Interestingly, the chloride and sulfate concentrations in the test 2 leachates are slightly lower than in the test 1 leachates. The leachate sodium contents are comparable for corresponding ashes. One might expect that if a corrosive component, such as sodium chloride or perhaps sodium sulfate, were present in the test 2 combustion gas, as implicated by the SASS and HCl train results discussed above, evidence of this component would appear in the ash leachates, particularly the cyclone ash leachate. An alternative explanation would be that the component was present in the vapor phase at the cyclone temperatures, although this seems unlikely.

TABLE 3-9. ASH STREAM LEACHATE TRACE ELEMENT AND LEACHABLE ANION ANALYSIS RESULTS

	Concentration (mg/l)			
	Test 1 (coal fuel)		Test 2 (coal/PET fuel)	
Component[a]	Bottom ash leachate	Cyclone hopper ash leachate	Bottom ash leachate	Cyclone hopper ash leachate
Elements				
Aluminum	0.50	1,500	14	1100
Antimony	<0.004	0.15	0.20	0.05
Arsenic	0.03	4.1	0.01	0.20
Barium	0.06	2.1	0.30	0.05
Beryllium	<0.001	0.32	<0.002	0.07
Bismuth	<0.001	0.005	<0.002	<0.001
Boron	0.20	1.8	0.40	0.20
Bromine	0.03	0.51	0.08	0.08
Cadmium	<0.001	0.17	0.004	0.10
Calcium	110	1.8	53	1.9
Cerium	0.001	0.85	<0.002	0.20
Cesium	<0.001	0.05	<0.002	0.02
Chromium	0.02	3.7	0.06	1.0
Cobalt	<0.001	7.4	<0.003	1.0
Copper	0.01	18	0.03	6.0
Dysprosium	<0.001	0.63	<0.002	0.02
Erbium	<0.001	0.30	<0.002	0.008
Europium	<0.001	0.09	<0.002	0.01
Gadolinium	<0.001	0.23	<0.002	0.03
Gallium	0.01	6.5	0.09	5.0
Germanium	0.002	0.22	0.01	0.07
Hafnium	<0.001	0.03	<0.002	0.004
Holmium	<0.001	0.40	<0.002	0.01
Iodine	0.002	0.008	0.01	0.001
Iron	0.06	1100	0.60	540
Lanthanum	<0.001	1.2	<0.002	0.30
Lead	<0.004	0.27	0.009	0.10
Lithium	3.0	4.7	0.07	4.4
Lutetium	<0.001	0.03	<0.002	0.002
Magnesium	4.7	110	0.90	96

(continued)

[a] Gold, iridium, osmium, palladium, platinum, rhenium, rhodium, and ruthenium were also analyzed for but were present at less that the method detection limit (0.001 to 0.002 mg/l) in all samples.

TABLE 3-9. (continued)

	Concentration (mg/l)			
	Test 1 (coal fuel)		Test 2 (coal/PET fuel)	
Component[a]	Bottom ash leachate	Cyclone hopper ash leachate	Bottom ash leachate	Cyclone hopper ash leachate
Manganese	0.002	24	0.005	18
Mercury	0.002	<0.001	<0.001	<0.001
Molybdenum	0.10	0.22	0.50	0.02
Neodymium	<0.001	0.72	<0.002	0.20
Nickel	0.01	4.0	0.02	0.80
Niobium	<0.001	0.19	0.003	0.005
Phosphorus	0.10	0.02	0.30	<0.01
Potassium	7.3	140	5.1	56
Praseodymium	<0.001	0.34	<0.002	0.08
Rubidium	0.008	0.63	0.02	0.10
Samarium	<0.001	0.76	<0.002	0.06
Scandium	<0.001	0.85	<0.002	0.10
Selenium	0.10	0.80	0.10	0.20
Silicon	4.0	89	5.0	210
Silver	<0.002	0.008	<0.004	<0.001
Sodium	>10	170	7.1	170
Strontium	0.60	24	3.0	4.0
Sulfur	110	15,300	90	3,900
Tantalum	<0.001	0.03	<0.002	0.005
Tellurium	<0.001	0.01	<0.002	0.001
Terbium	<0.001	0.06	<0.002	0.007
Thallium	<0.001	0.21	<0.002	0.09
Thorium	<0.001	0.31	<0.002	0.01
Thulium	<0.001	0.04	<0.002	0.002
Tin	<0.001	0.02	<0.002	0.003
Titanium	0.30	4.4	0.20	0.50
Tungsten	<0.001	0.03	0.02	<0.003
Uranium	<0.001	0.69	<0.002	0.05
Vanadium	0.02	7.4	0.05	0.30
Ytterbium	<0.001	0.27	<0.002	0.03
Yttrium	0.001	1.2	0.009	0.50
Zinc	0.03	44	0.06	12
Zirconium	0.003	0.95	0.01	0.01

(continued)

[a] Gold, iridium, osmium, palladium, platinum, rhenium, rhodium, and ruthenium were also analyzed for but were present at less that the method detection limit (0.001 to 0.002 mg/l) in all samples.

TABLE 3-9. (continued)

	Concentration (mg/l)			
	Test 1 (coal fuel)		Test 2 (coal/PET fuel)	
Component[a]	Bottom ash leachate	Cyclone hopper ash leachate	Bottom ash leachate	Cyclone hopper ash leachate
Anions				
Chloride	2.6	300	1.3	180
Fluoride	0.25	0.46	0.10	1.8
Nitrate	<1.0	<10	<1.0	<10
Nitrite	<1.0	<10	<1.0	<10
Phosphate	<1.0	<10	<1.0	<10
Sulfate	300	19,000	220	12,000
Sulfite	20	5,000	20	5,000

[a] Gold, iridium, osmium, palladium, platinum, rhenium, rhodium, and ruthenium were also analyzed for but were present at less that the method detection limit (0.001 to 0.002 mg/l) in all samples.

3.3 ORGANIC POLLUTANT DISCHARGE CONCENTRATIONS

Organic analyses were performed on specified flue gas and ash stream samples according to an extended EPA Level 1 protocol (Ref. 3-8) as outlined in Appendix A. The SASS train composite particulate, organic module sorbent (XAD-2), and organic module condensate (OMC) samples, and the bottom ash and cyclone hopper ash samples were extracted with methylene chloride in a Soxhlet apparatus. The extracts (the XAD-2 and OMC extracts were combined) were then subjected to total chromatographable organic (TCO) and gravimetric (GRAV) analyses to determine the total concentration of organics within the 100° to 300°C (212° to 575°F), and greater than 300°C (572°F) boiling point ranges, respectively. Infrared (IR) spectra of the GRAV residues of the extracts were also obtained. The XAD-2 and cyclone hopper ash extracts were subjected to further separation by liquid column (LC) chromatography followed by TCO, GRAV, and IR analysis of eluted fractions. In addition the SASS train extract samples were analyzed for the 58 semivolatile organic priority pollutants (a category which contains several polynuclear aromatic hydrocarbon (PAH) species) by gas chromatography/mass spectrometry (GC/MS) in accordance with EPA Method 625 (Ref. 3-9). Table 3-10 lists the compounds sought in this analysis and their method detection limits. The volatile organic sampling train (VOST) sorbent traps taken for test 2 were analyzed per VOST protocol (Ref. 3-10) for the volatile organic priority pollutants by GC/MS in accordance with EPA Method 624.

Results of all these analyses are discussed in the following subsections.

TABLE 3-10. COMPOUNDS SOUGHT IN THE GC/MS AND THEIR DETECTION LIMITS (ng/μl INJECTED)

Acid Compounds

2,4,6-trichlorophenol	5	2-nitrophenol	5
p-chloro-m-cresol	5	4-nitrophenol	20
2-chlorophenol	5	2,4-dinitrophenol	20
2,4-dichlorophenol	5	4,6-dinitro-o-cresol	20
2.4-dimethylphenol	5	pentachlorophenol	5
		phenol	1

Base Neutral Compounds

1.2,4-trichlorobenzene	1	benzo(c)phenanthrene	40
1,2-dichlorobenzene	1	bis(2-chloroethoxy)methane	1
1,2-diphenylhydrazine (as azobenzene)	1	bis(2-chloroethyl)ether	1
		bis(2-chloroisopropyl)ether	1
1,3-dichlorobenzene	1	bis(2-ethylhexyl)phthalate	1
1,4-dichlorobenzene	1	butyl benzyl phthalate	1
2,4-dinitrotoluene	1	chrysene	1
2,6-dinitrotoluene	1	di-n-butyl phthalate	1
2-chloronaphthalene	1	di-n-octyl phthalate	1
3,3'-dichlorobenzidine	5	dibenzo(a,h)anthracene	1
3-methyl cholanthrene	40	dibenzo(c,g)carbazole	40
4-bromophenyl phenyl ether	1	diethyl phthalate	1
4-chlorophenyl phenyl ether	1	dimethyl phthalate	1
7,12-dimethyl benz(a)anthracene	40	fluoranthene	1
N-nitrosodi-n-propylamine	5	fluorene	1
N-nitrosodimethylamine	NA	hexachlorobenzene	1
N-nitrosodiphenylamine	1	hexachorobutadiene	1
acenaphthene	1	hexachlorocyclopentadiene	1
acenaththylene	1	hexachloroethane	1
anthracene	1	indeno(1,2,3-cd)pyrene	1
benzo(ghi)perylene	5	isophorone	1
benzidine	20	naphthalene	1
benzo(b)fluoranthene	1	nitrobenzene	1
benzo(k)fluoranthene	1	perylene	40
benzo(a)anthracene	1	phenanthrene	1
benzo(a)pyrene	1	pyrene	1

3.3.1 TCO, GRAV, GC/MS, and IR Analyses of Sample Total Extracts

Table 3-11 summarizes the results of the organic analyses of the SASS train samples for each test performed. As shown in the table the SASS train sorbent module accounted for all the flue gas total organic emissions. Total organic emissions for both tests were comparable and dominated (about 90 percent in both cases) by the nonvolatile fraction.

However, emissions of the several semivolatile organic priority pollutants detected were significantly higher for test 2 with the waste plastic added to the fuel. Only naphthalene and a phthalate were detected in the test 1 sorbent module extract; two additional PAH's, phenol, and two additional phthalates were present in the test 2 extracts. Phthalates are common contaminants in SASS train samples; levels comparable to those reported in Table 3-11 are often ascribed to contamination. However, the fact that the levels detected in the test 2 samples were generally significantly higher than those in the test 1 samples, and that phthalates are expected to be found in PET and its combustion products, suggest that these compounds may actually have been present in the test 2 flue gas.

Table 3-12 summarizes results of the GRAV organic analyses of the bottom ash and cyclone hopper ash extract samples. For test 1 only the cyclone hopper ash contained measurable levels of nonvolatile organics. For test 2, the organic content of the bottom ash increased, although that of the cyclone hopper ash was about half that for test 1. The total ash loading was less for test 2 than for test 1. In test 1, the total ash was 13.5 percent of fuel feed whereas ash was only 8.2 percent in test 2. For both tests, cyclone ash was about 3 percent of total ash.

TABLE 3-11. TOTAL ORGANIC AND SEMIVOLATILE ORGANIC PRIORITY POLLUTANT EMISSIONS (μg/dscm)

Component	Test 1 (coal fuel)	Test 2[a] (coal/PET fuel)
Total semivolatile organics (C_7 to C_{16}) by TCO		
XAD-2 + OMC	75	120
Total nonvolatile organics (C_{16+}) by gravimetry		
Composite particulate	<300	<400
XAD-2 + OMC	875	1,080
Total	875	1,080
Total organics:	950	1,200
Semivolatile organic priority pollutants (XAD-2 + OMC)		
Naphthalene	2.2	16
Phenanthrene	<0.4	3.0
Fluoranthene	<0.4	2.2
Phenol	<0.4	20
Bis(2-ethylhexyl)phthalate	<0.4	4.2
Diethyl phthalate	<0.4	6.0
Di-n-butylphthalate	<0.4	0.4
Other semivolatile organic priority pollutants	<0.4	<0.4

[a] TCO and GC/MS results represent the average of duplicate analyses

TABLE 3-12. ASH STREAM TOTAL ORGANIC CONTENT (mg/kg ash)

Sample	Total nonvolatile organics by gravimetry	
	Test 1 (coal fuel)	Test 2 (coal/PET fuel)
Bottom ash	<80	220
Cyclone hopper ash	1,100	500

Table 3-13 presents a summary of the IR spectra of the GRAV residue of each sample total extract. The spectra for corresponding samples from both tests were quite similar. The table shows that spectra of the composite particulate and the bottom ash extract samples for both tests suggest only the presence of aliphatic hydrocarbons in these samples (although oxygenates may be present in the composite particulate from the coal/PET fuel test). Sorbent module extracts from both tests strongly suggest the presence of both aliphatic hydrocarbons and oxygenates such as carboxylic acids, alcohols, aldehydes, and/or ketones. The presence of aliphatic hydrocarbons and some oxygenates is also suggested by the spectra of the cyclone ash extracts from both tests.

3.3.2 Liquid Chromatography Fractionation of Sample Extracts

The sorbent module (XAD-2 + OMC) and cyclone hopper ash extracts from both tests contained greater than 15 mg of total organic, so they were further analyzed by separation into seven polarity fractions via liquid column (LC) chromatography on silica gel. Results are shown in Tables 3-14 through 3-17 for the test 1 and test 2 sorbent module extracts and the test 1 and test 2 cyclone hopper ash extracts, respectively.

TABLE 3-13. TOTAL EXTRACT IR SPECTRA SUMMARY

	Test 1 (coal fuel)				Test 2 (coal/PET fuel)			
Sample	Wave Number (cm^{-1})	Intensity[a]	Assignment	Possible compound categories present	Wave Number (cm^{-1})	Intensity[a]	Assignment	Possible compound categories present
Composite particulate	2920	S	CH alkyl	Aliphatic hydrocarbons	2920	S	CH alkyl	Aliphatic hydrocarbons, possibly aldehydes or ketones
	2840	S	CH alkyl		2860	M	CH alkyl	
					1730	M	C=O stretch	
XAD-2 + OMC	3650-2300	M	O-H stretch	Aliphatic hydrocarbons; oxygenated hydrocarbons such as carboxylic acids, aldehydes , ketones, and/or alcohols	3850-2300	W	O-H stretch	Aliphatic hydrocarbons; oxygenated hydrocarbons such as carboxylic acids, aldehydes, ketones, and/or alcohols
	2970	S	CH alkyl		2960	M	CH alkyl	
	2920	S	CH alkyl		2920	M	CH alkyl	
	2860	M	CH alkyl		2860	M	CH alkyl	
					1770			
	1740	M	C=O stretch		1740	W	Not assigned	
	1600	W	Not assigned		1600	S	C=O stretch	
	1580	W	Not assigned			W	Not assigned	
	1450	M	C-H, O-H bend		1450	M	C-H, O-H bend	
	1370	W	C-H, O-H bend		1370	W	C-H, O-H bend	
	1260	M	C-O stretch		1260	M	C-O stretch	
	1160	M	C-O stretch					
	1090	M	C-O stretch		1080	M	C-O stretch	
	810	M	Not assigned		800	M	Not assigned	
	770	W	Not assigned					
	750	W	Not assigned					
	720	W	Not assigned		720	W	Not assigned	
	630	W	Not assigned					
Bottom ash	2920	S	CH alkyl	Aliphatic hydrocarbons	2930	S	CH alkyl	Aliphatic hydrocarbons
	2840	M	CH alkyl					
Cyclone hopper ash	3850-2300	W	O-H stretch	Aliphatic hydrocarbons; oxygenated hydrocarbons such as carboxylic acids , aldehydes, ketones, and/or alcohols	2920	S	CH alkyl	Aliphatic hydrocarbons; oxygenated hydrocarbons such as aldehydes and/or ketones
	2940	S	CH alkyl		2860	M	CH alkyl	
	2860	M	CH alkyl		1770	M	Not assigned	
	1770	M	Not assigned		1740-1680	M	C=O stretch	
	1740	S	C=O stretch		1600	M	Not assigned	
	1600	M	Not assigned		1480	M	C-H bend	
	1460	M	C-H, O-H bend		1380	W	C-H bend	
	1380	W	C-H, O-H bend					
	1270	W	C-O stretch					
	1120	W	Not assigned					
	760	M	Not assigned					

[a] S = strong, M = moderate, W = weak.

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TABLE 3-14. LC FRACTIONATION OF THE TEST 1 SORBENT MODULE EXTRACT

	TCO (mg)	GRAV (mg)	TCO + GRAV (mg)	Concentration (mg/dscm)
Total sample	20	24	76	0.95
Taken for LC	1.1	14	15	0.55
Recovered	0.6	7.9	8.5	0.31

	TCO (mg)		GRAV (mg)			
Fraction	Analyzed[a]	Corrected to total sample	Analyzed[a]	Corrected to total sample	TCO + GRAV (mg)	Concentration (mg/dscm)
1	0.6	1.0	1.5	2.6	3.6	0.13
2	<0.1	<0.2	<0.4	<0.7	<0.7	<0.03
3	<0.1	<0.2	<0.4	<0.7	<0.7	<0.03
4	<0.1	<0.2	<0.4	<0.7	<0.7	<0.03
5	<0.1	<0.2	0.8	1.4	1.4	0.05
6	<0.1	<0.2	2.6	4.5	4.5	0.16
7	<0.1	<0.2	3.0	5.2	5.2	0.19
Total	0.6	1.0	7.9	13.7	14.7	0.53

[a] Blank corrected

TABLE 3-15. LC FRACTIONATION OF THE TEST 2 SORBENT MODULE EXTRACT

	TCO (mg)	GRAV (mg)	TCO + GRAV (mg)	Concentration (mg/dscm)
Total sample	3.2	27	30	1.2
Taken for LC	1.6	13.5	15	0.60
Recovered	<0.2	13.6	14	0.56

	TCO (mg)		GRAV (mg)			
Fraction	Analyzed[a]	Corrected to total sample	Analyzed[a]	Corrected to total sample	TCO + GRAV (mg)	Concentration (mg/dscm)
1	<0.2	<0.4	3.2	6.4	6.4	0.26
2	<0.1	<0.2	<0.4	<0.8	<0.8	<0.03
3	<0.1	<0.2	1.2	2.4	2.4	0.10
4	<0.1	<0.2	1.0	2.0	2.0	0.08
5	<0.1	<0.2	0.6	1.2	1.2	0.05
6	<0.1	<0.2	3.8	7.6	7.6	0.30
7	<0.1	<0.2	3.8	7.6	7.6	0.30
Total	<0.2	<0.4	13.6	27.2	27.2	1.09

[a] Blank corrected

TABLE 3-16. LC FRACTIONATION OF THE TEST 1 CYCLONE HOPPER ASH EXTRACT

	TCO[a] (mg)	GRAV (mg)	TCO + GRAV (mg)	Concentration (mg/kg)
Total sample		55	55	1,100
Taken for LC		22	22	440
Recovered		28	28	560

	TCO[a] (mg)		GRAV (mg)			
Fraction	Analyzed	Corrected to total sample	Analyzed[b]	Corrected to total sample	TCO + GRAV (mg)	Concentration (mg/kg)
1			5.0	12	12	240
2			0.8	2	2	40
3			2.2	6	6	120
4			1.8	4	4	80
5			2.2	6	6	120
6			11.6	29	29	580
7			4.0	10	10	200
Total			27.6	69	69	1,400

[a] TCO not performed, sample collected at high temperature

[b] Blank corrected

TABLE 3-17. LC FRACTIONATION OF THE TEST 2 CYCLONE HOPPER ASH EXTRACT

	TCO[a] (mg)	GRAV (mg)	TCO + GRAV (mg)	Concentration (mg/kg)
Total sample		25	25	500
Taken for LC		22	22	440
Recovered		27	27	600

	TCO[a] (mg)		GRAV (mg)			
Fraction	Analyzed	Corrected to total sample	Analyzed[b]	Corrected to total sample	TCO + GRAV (mg)	Concentration (mg/kg)
1			5.0	5.7	5.7	110
2			1.8	2.0	2.0	40
3			3.4	3.9	3.9	78
4			2.4	2.7	2.7	54
5			2.6	3.0	3.0	60
6			8.4	9.5	9.5	190
7			3.0	3.4	3.4	68
Total			26.6	30.2	30.2	600

[a] TCO not performed, sample collected at high temperature
[b] Blank corrected

In the fractionations of the sorbent module extracts, recovery of the volatile components (TCO compounds) was relatively poor, at 13 percent for test 1 and 55 percent for test 2. However, recovery of the nonvolatile components (GRAV compounds) was acceptable, ranging from 56 to 127 percent.

Tables 3-14, 3-15, and 3-16 show that the largest organic fractions for the sorbent module extracts for both test 1 (coal fuel) and test 2 (coal/PET fuel) and the test 1 cyclone hopper ash extract were LC 1, which normally contains aliphatic hydrocarbons, and LC 6 and 7, which normally contain oxygenated compounds. The distribution of organics among LC fractions was quite similar for all three samples. Table 3-17 shows that the distribution of organics among LC fractions was more uniform for the test 2 cyclone hopper ash extract, though LC 6 contained the largest amount of organic.

Table 3-18 presents a summary of the IR spectra for the extract LC fractions. The table shows that the spectra for corresponding sample/fractions for both tests were essentially the same. The spectra for the sorbent module extract fractions suggest only the presence of aliphatic hydrocarbons in all LC fractions, except LC 6, which apparently contains some oxygenated compounds. Comparing the sorbent module fraction spectra with the total extract spectra in Table 3-13 shows that many absorbances in the total extract are not accounted for within the LC fractions. Evidently the dilution attendant with the fractionation is such that several absorbances become too weak for these samples.

The spectra for the cyclone hopper ash fractions suggest only aliphatic hydrocarbons in LC 1, 2, and 3. Aldehydes are possibly present in LC 4 of the test 2 cyclone hopper ash extract. Oxygenates are present in LC 5, 6, and 7 of both test cyclone hopper ash extracts. Aldehydes and ethers are

TABLE 3-18. IR SPECTRA SUMMARY FOR LC FRACTIONS OF THE SORBENT MODULE AND CYCLONE HOPPER ASH EXTRACTS

	Test 1 (coal fuel)				Test 2 (coal/PET fuel)			
Sample/ fraction	Wave number (cm^{-1})	Intensity[a]	Assignment	Possible compound categories present	Wave number (cm^{-1})	Intensity[a]	Assignment	Possible compound categories present
XAD-2 Extract								
1	2930	S	CH alkyl	Aliphatic hydrocarbons	2930	S	CH alkyl	Aliphatic hydrocarbons
2		No peaks				No peaks		
3		No peaks				No peaks		
4		No peaks			2915	S	CH alkyl	Aliphatic hydrocarbons
5		No peaks			2940	S	CH alkyl	Aliphatic hydrocarbons
6	2935 1745	S S	CH alkyl C=0 stretch[b]	Aliphatic hydrocarbons, possibly some oxygenated compounds	2940 1725	S S	CH alkyl C=0 stretch[b]	Aliphatic hydrocarbons, possibly some oxygenated compounds
7	2950	S	CH alkyl	Aliphatic hydrocarbons	2940	S	CH alkyl	Aliphatic hydrocarbons
Cyclone Ash Extract								
1	2940 1468 1384	S M W	CH aklyl CH_2 No assigned	Aliphatic hydrocarbons	2940 1460	S W	CH alkyl CH_2	Aliphatic hydrocarbons
2	2940	S	CH aklkyl	Aliphatic hydrocarbons	2940	S	CH alkyl	Aliphatic hydrocarbons
3	2940 1462	S M	CH alkyl CH_2	Aliphatic hydrocarbons	2940 1460	S M	CH alkyl CH_2	Aliphatic hydrocarbons
4	2940 1465	S M	CH alkyl CH_2	Aliphatic hydrocarbons	2940 1775 1705 1460	S W M M	CH alkyl Not assigned C=0 stretch[b] CH_2	Aldehydes
5	2940 1783 1710 1600 1465	S M S M M	CH alkyl Not assigned C=0 stretch[b] Not assigned CH_2	Aldehydes and/or ethers	2940 1780 1718 1600 1460 1300	S S S S M M	CH alkyl Not assigned C=0 stretch Not assigned CH_2 C-0 stretch	Aldehydes and/or ethers
6	3300 2940 1780 1730 1600 1455 1290	W S M S M M M	0-H stretch CH alkyl Not assigned C=0 stretch Not assigned CH_2 C-0 stretch	Carboxylic acids, alcohols, esters, and/or ketones	3300 2945 1782 1735 1600 1460	W S M S M M	0-H stretch CH alkyl Not assigned C=0 stretch[b] Not assigned CH_2	Carboxylic acids, alcohols, esters, and/or ketones
7	3350 2943 1725 1600 1460 1285	S S S S W W	0-H stretch CH alkyl C=0 stretch Not assigned CH_2 C-0 stretch	Carboxylic acids, alcohols, esters, and/or ketones	3400 2943 1725 1600 1458 1275	S S S S M W	0-H stretch CH alkyl C=0 stretch Not assigned CH_2 C-0 stretch	Carboxylic acids, alcohols, esters, and/or ketones

[a] S: Strong, M: Moderate, W: Weak
[b] Tentative assignment

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possible in LC 5, and alcohols, esters, ketones, and carboxylic acids are most likely in LC 6 and 7. Comparing the cyclone ash fraction spectra to the total extract spectra in Table 3-13 shows that, in contrast to the case for the sorbent module extracts, almost all absorbances in the total sample extracts are accounted for in the fraction spectra.

The results of the LC fractionation of the extract samples suggest that the organic sorbent module extracts for both tests were composed of roughly 25 to 35 percent aliphatic hydrocarbons (LC's 1 and 3), 40 percent less polar oxygenated hydrocarbons (LC's 4, 5, and 6), and 25 to 35 percent more polar oxygenates (LC 7).

The results of the LC fractionation of the cyclone ash extracts combined with the IR spectra of eluted fractions suggests that these were composed of 30 to 40 percent aliphatic hydrocarbons (LC's 1, 2, and 3) 15 to 20 percent less polar oxygenated hydrocarbons such as aldehydes and ethers (LC's 4 and 5), and 40 to 55 percent more polar oxygenates such as carboxylic acids, alcohols, and ketones (LC's 6 and 7) for both tests.

3.3.3 Volatile Organic Compound Emissions

Table 3-19 summarizes the analysis results of the VOST train samples collected during test 2 (VOST was run only for this test). As noted in the table, several chlorinated C_1 and C_2 aliphatics, chlorobenzene, toluene, and ethylbenzene were detected in the flue gas at levels in the order 1 to order 10 µg/dscm range. The levels of the aromatic hydrocarbons (toluene and ethylbenzene) noted are typical of what has been seen in recent VOST tests of combustion sources (Refs. 3-5, 3-7, and 3-11). The source of the chlorinated hydrocarbons is not clearly understood, although these compounds do arise whenever chlorine containing fuels are burned, or chlorine, even inorganic

TABLE 3-19. FLUE GAS VOLATILE ORGANIC COMPOUND EMISSIONS

Compound[b]	Flue gas emission concentration (μg/dscm)[a]		
	Tenax trap	Tenax/ charcoal trap	Total
Chloromethane	0.5	0.5	1.0
Chloroform	3.4	1.1	4.5
1,2-dichloroethane	<0.25	2.0	2.0
Trichloroethylene	24	<0.25	24
Tetrachloroethylene	2.5	<0.25	2.5
Toluene	7.3	6.7	14
Chlorobenzene	7.5	<0.25	7.5
Ethylbenzene	0.7	<0.25	0.7

[a] Field blank corrected

[b] Bromomethane, vinyl chloride, chloroethane, methylene chloride, 1,1-dichloroethylene, 1,1-dichloroethane, t-1,2-dichloroethylene, 1,1,1-trichloroethane, carbon tetrachloride, dichlorobromomethane, 1,2-dichloropropane, t-1,3-dichloropropene, chlorodibromomethane, 1,1,2-trichloroethane, c-1,3-dichloropropene, benzene, 2-chloroethyl vinyl ether, bromoform, 1,1,2,2-tetrachloroethane, xylenes, allyl chloride, ethylene oxide, propylene oxide, and 2-nitropropane were also analyzed for and not detected above a detection limit of 0.25 μg/dscm

chlorides, is introduced into the combustion process. It is interesting that these compounds are detected in the test 2 flue gas, the same test with apparent chloride introduction into the SASS train, and unaccountably high (perhaps again due to extraneous flue gas chloride) chloride emissions measured with the HCl train. The chlorine content of the fuel at 0.2 percent seems too low to have given rise to the levels of the chlorinated compounds measured.

REFERENCES FOR SECTION 3

3-1. DeRosier, R., "Environmental Assessment of a Watertube Boiler Firing a Coal/Oil Mixture," Acurex Draft Report TR-81-87/EE, March 1984.

3-2. DeRosier, R., "Environmental Assessment of a Crude-Oil Heater Using Staged Air Lances for NO_x Reduction," EPA 600/7-84-074 a/b, NTIS PB84-223031/-223049, July 1984.

3-3. Castaldini, C., et al., "Environmental Assessment of NH_3 Injection for an Industrial Package Boiler," EPA 600/7-86-005 a/b, NTIS PB86-159852/"unassigned", February 1986.

3-4. DeRosier, R. and L. R. Waterland, "Environmental Assessment of a Watertube Boiler Firing Coal-Water Slurry," EPA 600/7-86-004 a/b, NTIS PB86-159845/"unassigned", February 1986.

3-5. VanBuren, D., and L. R. Waterland, "Environmental Assessment of a Coal-Water-Slurry-Fired Industrial Boiler," Acurex Draft Report TR-84-155/EE, February 1985.

3-6. Castaldini, C., et al., "Environmental Assessment of an Enhanced Oil Recovery Steam Generator Equipped with a Low-NO_x Burner," EPA 600/7-86-003 a/b, NTIS PB86-159837/"unassigned", February 1986.

3-7. Castaldini, C., et al., "Environmental Assessment of an Enhanced Oil Recovery Steam Generator Equipped with the EPA Low NO_x Burner," Acurex Draft Report TR-85-174/EED, January 1985.

3-8. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)", EPA 600/7-78-201, NTIS PB293795, October 1978.

3-9. 44 CFR 69532, December 3, 1979.

3-10. "Protocol for the Collection and Analysis of Volatile POHC's Using VOST," EPA-600/8-84-007, NTIS PB84-170042, March 1984.

3-11. Castaldini, C., S. Unnasch, and H. B. Mason, "Engineering Assessment of Hazardous Waste Cofiring in Industrial Boilers," Acurex Technical Report TR-84-159/EED, May 1984.

SECTION 4

ENVIRONMENTAL ASSESSMENT

This section discusses the potential environmental significance of the boiler tested and discusses the results of the bioassay testing of flue gas and solid waste stream samples collected from the boiler burning both coal and the coal/waste polyethylene terephthalate (PET) mixture tested. As a means of ranking species discharged for possible further monitoring or evaluation flue gas stream pollutant concentrations are compared to occupational exposure guidelines, and solid waste stream leachate concentrations are compared to water quality criteria. Bioassay analyses were conducted as a more direct measure of the potential health effects of the emissions and discharge streams. Both of these analyses are aimed at identifying and providing the basis for ranking pollutant species and discharge streams for further consideration.

4.1 DISCHARGE ASSESSMENT

To obtain a measure of the potential significance of the discharge streams analyzed in this test program, for further monitoring and evaluation discharge stream concentrations were compared to occupational exposure guidelines, generally either the time-weighted-average threshold limit values (TLV's) defined by the American Conference of Governmental Industrial Hygienists (AGCIH) (Ref. 4-1) or the 8-hour time-weighted-average exposure limits established by the Occupational Safety and Health Administration (OSHA) (Ref. 4-2). For the solid waste discharges (bottom ash and cyclone hopper ash) the indices used were the health effects-based water quality criteria (Ref. 4-3).

The comparisons of discharge stream species concentration to these indices should only be used for ranking pollutant discharge levels for further testing and analyses.

Table 4-1 lists those pollutants emitted in the flue gas at levels greater than 10 percent of their occupational exposure guideline. As noted in the table, analyzed flue gas concentrations of chromium, sodium, nickel, iron, and lead for test 2 (coal/PET fuel) were significantly larger than their occupational exposure guidelines. However, as discussed in Section 3.2, the high analyzed levels for all these elements except lead in test 2 are questionable, and would require further testing to clarify. Actual emission levels for all these elements except lead are expected to be more comparable to those measured for test 1, as is the case for the other elements noted in the table.

The higher lead emissions in test 2 for the coal/PET fuel are regarded as an actual increase. This increase reflects the significantly increased lead content of the coal/PET fuel compared to the coal alone. The PET additive is apparently the source of this added lead although no component of PET has been identified as containing lead. The significance of these increased emissions deserves further study, especially in light of the fact that the lead emission concentration noted in Table 4-1 for test 2 represents an estimate based on estimated 1 to 3 μm SASS particulate emission rate and

TABLE 4-1. FLUE GAS POLLUTANTS EMITTED AT LEVELS EXCEEDING 10 PERCENT OF THEIR OCCUPATIONAL EXPOSURE GUIDELINE

Pollutant	Flue gas concentration (µg/dscm)		Occupational exposure guideline ($\mu g/m^3$)[a]
	Test 1 (coal)	Test 2 (coal/PET)	
Major constituents:			
NO_x (as NO_2)	2.7×10^5	2.8×10^5	6,000
SO_2	1.21×10^6	1.46×10^6	5,000
SO_3	7,000	5,700	1,000
CO	1.05×10^5	6.4×10^4	55,000
HCl	--[b]	3.47×10^5	7,000[c]
Particulate	54,000	69,000	10,000[d]
Trace Elements:			
Chromium	10	5,170	50
Sodium	652	107,000	2,000[c]
Nickel	27	3,810	100
Iron	3,180	27,600	1,000
Lead	30	1,100	50[e]
Phosphorus	2,150	1,350	100
Arsenic	17	49	10
Aluminum	2,150	2,450	2,000
Lithium	>26	>14	25
Calcium	1,930	485	2,000
Beryllium	0.97	1.6	2
Silicon	>2,360	5,120	10,000[d]
Potassium	914	966	2,000[c]
Cobalt	3.0	41	100
Cadmium	2.5	18	50[c]
Vanadium	18	12	50
Copper	32	35	100[e]
Platinum	--[f]	0.52	2
Silver	2.6	1.8	10
Selenium	10	41	200
Barium	56	21	500

[a] Time-weighted-average TLV (Ref. 4-1) unless noted

[b] HCl sampled for test 2 only

[c] Ceiling limit

[d] For nuisance particulate

[e] 8-hour time-weighted average OSHA exposure limit (Ref. 4-2)

[f] Less than the method detection limit

the assumption that the 1 to 3 μm SASS particulate lead concentration was the same as that measured for the <1 μm particulate (as discussed in Section 3.2).

Lead emissions aside, test results indicate that iron, phosphorous, arsenic, and aluminum were emitted at levels exceeding their respective occupational exposure guidelines, for both tests. Emissions of these elements at levels up to about a factor of 20 greater than an occupational exposure guideline are noted. For comparison, the gaseous criteria pollutants SO_2 and NO_x were emitted at levels over 200 and almost 50 times their respective occupational exposure guidelines.

The HCl emission level noted for test 2 is also quite significant. However, again, this may have been due to extraneous introduction of an inorganic chloride compound in the flue gas. As noted in Section 3, the HCl (or more accurately, vapor phase inorganic chloride) levels measured were almost three times those expected, based on the chlorine content of the fuel.

In summary, emissions for both tests were comparable except for questionable increases in chromium, sodium, nickel, and iron emissions for test 2. However, lead emissions were increased significantly with the mixed coal/PET fuel. This significance of the increase deserves further study.

Table 4-2 lists those priority pollutants present in at least one ash stream leachate analyzed at levels exceeding their respective health-effects-based water quality criteria. As indicated, all of the priority pollutant trace elements except silver were present in at least one leachate (generally

TABLE 4-2. PRIORITY POLLUTANTS IN ASH LEACHATES AT CONCENTRATIONS EXCEEDING THEIR WATER QUALITY CRITERIA

Element	Bottom ash leachate concentration (μg/l)		Cyclone hopper ash leachate concentration (μg/l)		Water quality criterion (mg/l)[a]
	Test 1 (coal)	Test 2 (coal/PET)	Test 1 (coal)	Test 2 (coal/PET)	
Arsenic	0.030	0.010	4.1	0.20	2.2×10^{-5}[b]
Beryllium	<0.001	<0.002	0.32	0.070	3.7×10^{-5}[b]
Nickel	0.01	0.02	4.0	0.80	0.0134
Selenium	0.10	0.10	0.80	0.20	0.010
Chromium	0.02	0.06	3.7	1.0	0.050
Cadmium	<0.001	0.004	0.17	0.10	0.010
Thallium	<0.001	<0.002	0.21	0.09	0.013
Mercury	0.002	<0.001	<0.001	<0.001	1.44×10^{-4}
Lead	<0.004	0.009	0.27	0.10	0.050
Barium	0.06	0.30	2.1	0.05	1.0
Antimony	<0.004	0.20	0.15	0.05	0.146

[a] Ref. 4-3

[b] Water quality criterion based on cancer risk; level noted corresponds to increased lifetime risk of 10^{-5}

the test 1 cyclone hopper ash leachate) at levels above their water quality criteria. Levels of arsenic, beryllium, and selenium exceeded their water quality criteria in all leachates. Levels of all the elements except mercury in the table were present in the test 1 (coal fuel) cyclone hopper ash leachate at levels exceeding (sometimes greatly exceeding) their water quality criteria.

The cyclone hopper ash leachates generally contained significantly higher concentrations of the elements noted in Table 4-2 than did bottom ash leachates. Further, the test 2 (coal/PET fuel) cyclone hopper ash leachate had lower concentrations of all the elements noted in the table. This suggests that the additon of the waste PET to the boiler's coal fuel may have had the beneficial effect of decreasing leachable toxic trace elements in the cyclone hopper ash stream (e.g., perhaps by decreasing the leachability of elements in this discharge).

4.2 BIOASSAY RESULTS

Health effects bioassay tests were performed on the SASS organic sorbent (XAD-2) extracts, the bottom ash, and the cyclone hopper ash collected for both test 1 (coal fuel) and test 2 (coal/PET fuel). The bioassay tests performed (Ref. 4-4) were the Ames assay, based on the property of Salmonella typhinurium mutants to revert due to exposure to various classes of mutagens, and the cytotoxicity assay (CHO) with mammalian cells in culture to measure cellular metabolic impairment and death resulting from exposure to soluble toxicants.

Table 4-3 summarizes the results of these tests. The results suggest that the XAD-2 extracts were of moderate to high mutagenicity and toxicity

TABLE 4-3. BIOASSAY RESULTS

		Bioassay response[a]	
Test	Sample	Ames mutagenicity	CHO clonal toxicity
1 (coal)	XAD-2 extract	H	M
	Bottom ash	ND	ND
	Cyclone hopper ash	M/H	ND
2 (coal/PET)	XAD-2 extract	M	H/M
	Bottom ash	ND	ND
	Cyclone hopper ash	L/M	ND

[a] ND -- Nondetectable mutagenicity/toxicity
L -- Low mutagenicity/toxicity
M -- Moderate mutagenicity/toxicity
H -- High mutagenicity/toxicity

for both tests. The bottom ash had nondetectable mutagenicity and toxicity for both tests. The cyclone hopper ash had nondetectable toxicity for both tests. However this sample's mutagenicity apparently decreased from borderline moderate/high for test 1 (coal fuel) to borderline low/moderate for test 2 (coal/PET fuel). This observation is consistent with the decreased leachate concentrations of arsenic and beryllium noted in Table 4-2, and confirms that the addition of waste PET to the boiler's coal fuel may have had the beneficial effect of decreasing the potential environmental hazard posed by this discharge.

The positive Ames responses for the XAD-2 extracts noted above are typical for XAD-2 from SASS tests of combustion sources. Current studies sponsored by EPA's Industrial Environmental Research Laboratory/Research

Triangle Park are investigating whether such responses are due to artifact compounds formed when combustion product gas containing NO_x is passed over XAD-2 resin.

4.3 SUMMARY

A comprehensive emissions and discharge stream testing program was performed on a stoker coal-fired commercial boiler. Two tests were performed: one with the boiler firing its standard coal fuel (test 1) and one with a fuel mixture containing the standard coal with about 16 percent by weight of granulated waste polyethylene terephthalate (PET) beverage bottles added (test 2).

NO_x and total unburned hydrocarbon (TUHC) emissions from the boiler (corrected to 3 percent O_2) averaged 286 and 214 ppm and <2 and 3 ppm, respectively, for test 1 and 2, respectively. These apparent differences are not considered significant. Similarly, solid particulate emissions (downstream of the unit's cyclone collector) were comparable for both tests at 54 mg/dscm for test 1 and 69 mg/dscm for test 2. The emitted particle size distribution was also apparently unchanged between the two tests.

Sulfur oxides emission concentrations decreased with the coal/PET fuel in keeping with the lowered sulfur content of this fuel. SO_2 emissions decreased from 930 ppm in test 1 to 640 ppm in test 2 and SO_3 emissions decreased from 4.4 ppm in test 1 to 2.5 ppm in test 2 (all corrected to 3 percent O_2). On a mass emission basis, sulfur oxide mass output was nearly the same for the two tests. CO emissions were also decreased from an average of 184 ppm in test 1 to 81 ppm (corrected to 3 percent O_2) in test 2 due probably to higher excess air in test 2.

N_2O levels in the flue gas at 57 ppm for test 1 and 90 ppm for test 2 (3 percent O_2) corresponded to 20 to 40 percent of respective boiler NO_x emissions, in the range noted in other tests of external combustion sources.

HCl emissions were measured at 336 ppm (3 percent O_2) for test 2. This level is almost three times that which can be accounted for by the fuel input chlorine. Other evidence suggests that an inorganic chloride was introduced into the flue gas beyond that corresponding to the fuel input.

Emissions of most trace elements from the boiler were comparable for both tests with a few notable exceptions. Apparent emissions of chromium, iron, nickel and sodium were significantly higher for test 2. However, as noted above, the evidence available suggests that some corrosive compound such as sodium chloride was introduced into the boiler during this test. If this were the case the high levels of chromium, iron, and nickel apparently measured would be attributable to corrosion of the flue gas sampling train's stainless steel parts. The fact that the HCl emission measurement gave higher HCl emissions than could be accounted for by the fuel input supports the hypothesis that some unknown inorganic chloride source came into play for this test.

These factors aside, lead emissions from the boiler were significantly higher with the mixed coal/PET fuel than for the coal fuel alone. This emissions increase is directly attributable to the inexplicable lead content of the PET additive in the coal/PET fuel. This significance of the increased lead emission deserves further study, especially in light of the fact that the cited test 2 lead emission concentration represents an estimate as noted in Section 4.1 (and 3.2) above.

The trace element compostion of corresponding ash samples for both tests (flue gas particulate, bottom ash, and cyclone hopper ash) were comparable (with the exception of lead, discussed above). Aqueous leachates of the cyclone hopper ash samples had significantly higher trace element and leachable anion concentrations than aqueous leachates of bottom ash samples. The bottom ash leachate trace element and leachable anion concentrations were comparable for both tests. However, the cyclone hopper ash leachate for test 2 had consistently lower levels of most trace elements, especially the recognized toxic elements regulated as priority water pollutants, than the cyclone hopper ash leachate for test 1.

Total organic emissions from the boiler were comparable for both tests at 950 μg/dscm for test 1 and 1,200 μg/dscm for test 2. About 90 percent of the emitted organic was in the nonvolatile boiling point range (boiling point nominally greater than 300°C). Infrared spectromety and liquid column chromatography analyses suggest that flue gas organic emissions and the organic fraction of the cyclone hopper ash were composed chiefly of aliphatic hydrocarbons and oxygenerated hydrocarbons such as carboxylic acids, aldehydes, ketones, and/or alcohols for both tests. Only the presence of aliphatic hydrocarbons was indicated in the organic fraction of the bottom ash samples for both tests.

Of the semivolatile organic priority pollutants analyzed in flue gas samples, only the presence of naphthalene at a flue gas concentration of 2.2 μg/dscm was confirmed for test 1. Emissions of naphthalene were increased to 16 μg/dscm in test 2. In addition, emissions of phenanthrene, fluoranthene, and phenol were quantitated for test 2 at 3, 2.2, and 20 μg/dscm respectively. Several phthalate esters were detected in the test 2 flue gas at levels ranging from 0.4 to 6 µg/dscm. Such levels in SASS train samples are often described to contamination. However, since they were only detected in test 2 samples and would be expected with the combustion of PET, the levels measured are likely to represent actual emissions.

Flue gas sampling for volatile organic priority pollutants was performed in test 2 only. Several chlorinated C_1 and C_2 aliphatic chdrocarbons, chlorobenzene, toluene, and ethylbenzene were detected in the flue gas for this test at levels in the less than 1 to 25 µg/dscm range. The substituted benzene compounds (toluene and ethylbenzene) have been found to be relatively common constituents of combustion source flue gas. Similarly the chlorinated C_1 and C_2 aliphatics and chlorobenzene are common constituents when chlorine (even inorganic chlorides) is introduced into the combustion process. The fact that these chlorinated compounds were detected in test 2 further supports the above-noted hypothesis that an inorganic chloride was inadventently introduced into the boiler during test 2.

Results of bioassay testing of samples collected for both tests showed that the SASS train sorbent module extracts for both tests were of moderate to high Ames mutagenicity and CHO toxicity. This is a relatively common bioassay response for combustion source SASS tests. The bottom ash for both tests had nondetectable mutagenicity and toxicity. The cyclone hopper ash for both tests had nondetectable toxicity. However, this discharge's Ames mutagenicity decreased from moderate to high in test 1 (coal fuel) to low to moderate in test 2 (coal/PET fuel). This is consistent with the relatively lower trace element content (especially of arsenic and beryllium) of the test 2 cyclone ash aqueous leachate compared to the test 1 cyclone ash leachate.

REFERENCES FOR SECTION 4

4-1. "Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1983-84," American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1983.

4-2. OSHA Safety and Health Standards, 29 CFR 1910, Subpart Z.

4-3. 45 CFR 79318, November 28, 1980.

4-4. Brusick, D. J., and R. R. Young, "IERL-RTP Procedures Manual: Level 1 Environmental Assessment, Biological Tests," EPA-600/8-81-024, NTIS PB 81-228966, October 1981.

SECTION 5

TEST QUALITY ASSURANCE ACTIVITIES

Quality assurance (QA) activities implemented during this test included:

- Submitting a blind duplicate sample for inorganic trace element analyses by spark source mass spectrometry (SSMS), atomic absorption spectroscopy (AAS), and the other methods used
- Submitting a blind audit sample (NBS 1633a flyash) for inorganic trace element analyses by SSMS, AAS, and the other methods used
- Submitting a blind duplicate sample for ultimate analysis (C, H, O, N, S, Cl, ash, moisture)
- Analyzing the test 2 (coal/PET fuel) sorbent module extract in duplicate for total chromatographable organics (TCO) and for the semivolatile organic priority pollutants by gas chromatography/mass spectrometry (GC/MS)
- Analyzing blind EPA-EMSL audit SO_2 samples along with the laboratory analyses of the Method 8 samples collected

Results of these QA activities are discussed in the following subsections.

5.1 TRACE ELEMENT ANALYSES PRECISION AND ACCURACY

Duplicate samples of the boiler bottom ash from test 2 were submitted to the laboratory retained to perform inorganic analyses by SSMS, AAS, and other backup methods. Trace element concentrations for those elements quantitated by SSMS in each sample are given in Table 5-1. As indicated in the table,

TABLE 5-1. RESULTS OF SSMS ANALYSIS OF DUPLICATE TEST 2 BOTTOM ASH SAMPLES

Element	Concentration (μg/g)		Relative standard deviation (percent)
	Sample 1	Sample 2	
Antimony	15	29	45
Arsenic	7	8	9.4
Beryllium	24	10	58
Bromine	5	6	13
Cadmium	4	0.6	105
Cerium	42	49	11
Cesium	5	<0.2	135
Chlorine	36	230	103
Chromium	220	430	46
Cobalt	110	64	37
Copper	48	110	55
Dysprosium	8	7	9.4
Erbium	4	3	20
Europium	4	2	47
Gadolinium	8	5	33
Gallium	63	28	54
Germanium	4	3	20
Hafnium	5	3	35
Holmium	5	5	0
Iodine	0.7	3	88
Lanthanum	66	56	12
Lead	52	17	72
Lutetium	0.9	0.4	54
Manganese	72	42	37
Molybdenum	16	9	40
Neodymium	32	42	19
Nickel	150	220	27
Niobium	15	39	63
Praseodymium	10	22	53
Rubidium	25	22	9.0

(continued)

TABLE 5-1. (continued)

Element	Concentration (μg/g)		Relative standard deviation (percent)
	Sample 1	Sample 2	
Samarium	15	11	22
Scandium	41	73	40
Selenium	17	18	4.0
Silver	0.6	0.3	47
Strontium	510	400	17
Tantalum	5	2	66
Tellurium	0.3	<0.2	28
Terbium	3	2	28
Thallium	4	<0.4	116
Thorium	31	32	2.2
Thulium	1	1	0
Tin	2	2	0
Tungsten	4	2	47
Uranium	22	16	22
Vanadium	24	140	100
Ytterbium	7	4	39
Yttrium	62	41	29
Zinc	23	55	58
Zirconium	92	270	70
		Average	42

the relative standard deviation (RSD) of the results for the duplicate determination ranged from 0 to 135 percent, with an average of 42 percent. No project QA goal has been formally set for this measurement. However, Level 1 guidelines suggest that analytical techniques should be accurate to within a factor of 2 or 3 (Ref. 5-1). If the same goal is prescribed for method precision, then acceptable RSD's among replicate measurements would be 47 (factor of 2) to 71 (factor of 3) percent. The average precision obtained was within 42 percent, within this goal. Of 49 elements quantitated using SSMS, 33 measurements had RSD's of less than 47 percent, and 42 had RSD's of less than 71 percent.

Not all elements were quantitated using SSMS in the tests reported. Level 1 methodology specifies using cold vapor AAS for mercury. In addition, several elements were assayed at levels greater than the quantitation limit of the method by SSMS (and therefore reported as major components). For these elements AAS, or other appropriate techniques (e.g., turbidometric for sulfur, and colorimetric phosphorus), were used. Table 5-2 summarizes the method precision data obtained for elements quantitated by these other methods through duplicate sample analyses. As indicated in the table, RSD's ranged from 0 to 94 percent, with an overall average of 21 percent. RSD's for the AAS analyses only ranged from 0 to 55 percent with an average of 15.6 percent.

The project precision goal for mercury analysis by cold vapor AAS is 10 percent. This goal was not achieved as noted in Table 5-2. However, in sample 1, mercury was reported present at less than the method detection limit and in sample 2 at just twice the detection limit. Expecting to attain

TABLE 5-2. RESULTS OF DUPLICATE TEST 2 BOTTOM ASH ANALYSES BY AAS AND WET CHEMICAL METHODS

Element	Concentration (percent by weight) Sample 1	Concentration (percent by weight) Sample 2	Relative standard deviation[a] (percent)
Aluminum	16.43	16.84	1.7
Barium	0.0985	0.10	1.1
Calcium	2.59	1.14	55
Iron	3.86	3.94	1.5
Lithium	0.0054	0.0075	23
Magnesium	0.47	0.34	23
Mercury	<0.01	0.02	47
Phosphorus	0.10	0.09	7.4[b]
Potassium	1.14	1.20	3.6
Silicon	21.27	20.88	1.3
Sodium	0.52	0.42	15
Sulfur	0.54	0.11	94[c]
Titanium	0.74	0.74	0
		Average AAS RSD	15.6
		Average RSD	21.0

[a] Analysis method was AAS unless noted

[b] Titrimetric/colorimetric method

[c] Turbidimetric method

the QA objective of 10 percent precision at the method detection limit is not realistic.

The project precision goals for arsenic and antimony analyses by hydride generation AAS of SASS train impinger solutions is 30 percent (Ref. 3-2). If this level is accepted as appropriate for other AAS measurements, then all AAS measurements except that of calcium met this goal, as did both average RSD's. The RSD for the sulfur analysis also exceeded this goal, as well as the general (factor of 2 or 3) Level 1 goal.

In addition to duplicate analyses to establish method precision, an audit sample consisting of NBS 1633a flyash was submitted to the inorganic analysis laboratory to assess method accuracy. Table 5-3 summarizes the trace components analysis results as reported by SSMS. As indicated, the difference between the reported concentrations and the NBS values ranged from -12 to -95 percent, with one positive difference of 26 percent (i.e., in all except this one element the SSMS reported concentration was less, often significantly less, than the NBS value). The average absolute value of the differences was 66 percent.

The stated Level 1 accuracy goal is a factor of 2 to 3. This would correspond to a difference of -50 to +100 (factor of 2) to -67 to +200 percent. Of the 26 elements reported in Table 5-3, only 11 had implied accuracy of with a factor of 3, although the overall average implied accuracy was just with a factor of 3.

Table 5-4 summarizes the major component (from the initial SSMS analysis report) analysis results obtained using AAS on the audit sample submitted. Implied accuracy was much better using this technique. Here, negative differences ranged from -0.5 to -31 percent; while positive differences

TABLE 5-3. AUDIT SAMPLE (NBS 1633a FLYASH) SSMS ANALYSIS RESULTS

	Concentration (μg/g)		
Element	Reported	NBS certified value	Percent difference
Arsenic	18	145	-88
Cadmium	0.8	1.0	-20
Chromium	42	196	-79
Copper	14	118	-88
Nickel	31	127	-76
Lead	32	72.4	-56
Rubidium	28	131	-79
Selenium	13	10.3	26
Strontium	210	830	-75
Thorium	14	24.7	-43
Thallium	3	5.7	-47
Uranium	9	10.2	-12
Zinc	24	220	-89
		NBS value but not certified	
Antimony	5	7	-29
Barium	310	1,500	-79
Beryllium	5	12	-58
Cerium	30	180	-83
Cobalt	10	46	-78
Cesium	4	11	-64
Europium	1	4	-75
Gallium	19	58	-67
Hafnium	1	7.6	-87
Magnanese	9	190	-95
Molybdenum	6	29	-79
Scandium	15	40	-63
Vanadium	44	300	-85
Average absolute percent difference			66

TABLE 5-4. AUDIT SAMPLE (NBS 1633a FLYASH) AAS ANALYSIS RESULTS

Element	Concentration (percent by weight) Reported	Concentration (percent by weight) NBS certified value	Percent difference
Calcium	1.28	1.11	15.3
Iron	9.35	9.40	-0.5
Potassium	1.75	1.88	-6.9
Magnesium	0.47	0.455	3.3
Sodium	0.24	0.17	41.2
Silicon	21.43	22.8	-6.0
Mercury	0.000011	0.000016	-31.3
		NBS value but not certified	
Aluminum	13.57	14	-3.1
Titanium	0.76	0.8	-5.0
Average absolute percent difference[a]			10.2

[a] Excluding mercury, which has a different accuracy goal

ranged from 3.2 to 41 percent. The project QA accuracy goal for mercury analysis by cold vapor AAS is ±20 percent (Ref. 5-2). This goal was not achieved, as shown in Table 5-4. The project QA accuracy goal for arsenic and antimony analyses by hydride generation AAS is ±30 percent. If this latter is acceptable as appropriate for flame AAS, the technique used for all elements noted in Table 5-4 except mercury, this goal was achieved for all element analyses except sodium. The average absolute value of the differences was 12.5 percent, within the accepted accuracy goal.

Interestingly, elements for which AAS analytical accuracy was poor (calcium, sodium, and mercury) were generally the same as those for which precision was poor (see Table 5-3).

To summarize the results of test QA activities performed for the inorganic analyses:

- The average precision of the SSMS analyses as determined by duplicate sample analyses for 50 elements was 42 percent, within the assumed goal of 71 percent, however the precision for 7 of the 49 elements determined by SSMS exceeded 71 percent
- The average absolute accuracy of the SSMS analysis as determined by analysis of an audit sample was 66 percent just with an assumed goal of 67 percent; however, of 26 elements in the audit sample determined by SSMS, only 11 elements were reported within an assumed accuracy goal of -67 to +100 percent
- The average precision of the AAS analyses as determined by duplicate sample analyses was 21 percent within an assumed precision goal of 30 percent; of 11 elements determined by AAS, 9 measurements were within the assumed precision goal

- The average absolute accuracy of the flame AAS analyses as determined by analysis of an audit sample was 10 percent, well within an assumed accuracy goal of ±30 percent; of eight elements determined by flame AAS, seven were accurate within ±30 percent (in fact within ±20 percent)
- The accuracy of the mercury determination as measured by analysis of an audit sample was -31 percent, which failed the project QA goal of ±20 percent; the precision of the mercury determination, at 47 percent, exceeded the QA objective of 10 percent; however this occured right at the method detection limit of 0.01 μg/g.
- The precision of the phosphorus determination as determined by duplicate sample analysis was 7.4 percent, well within a realistic precision goal for this analysis
- The precision of the sulfur determination by turbidimetry was 94 percent, which would fail a realistic precision goal

Overall, the AAS and colorimetric (for phosphorus) analyses gave generally acceptable precision and accuracy. All except one determination (excluding the mercury analysis) met assumed goals; this approaches 90 percent completeness, another appropriate goal for these analyses. The mercury analyses had unacceptable accuracy, and the turbidimetric sulfur analysis had unacceptable precision.

The SSMS analyses had marginally acceptable precision (average precision within an assumed goal, and 42 of 49 individual determination within the same goal), but unacceptable accuracy (only 11 of 26 determinations within an appropriate accuracy goal). With respect to this latter, the audit sample submitted for analysis was an NBS flyash prepared in April 1979. NBS states that the long-term (>3 years) stability of the material had not been established. Conceivably, assay values for certain elements might have changed from those documented. Interestingly, the SSMS analyses, which had poor implied accuracy, were of elements present in trace quantities (order ppm). Still, it must be concluded that there were data quality problems in the SSMS analyses performed in this test.

These apparent data quality problems should have no effect on the conclusions derived from the SSMS analyses performed in this test. The trace element conclusions stated in Section 4.3 were:

- Boiler trace element emissions with the exception of lead were comparable for both tests
- The trace element composition of corresponding ash samples for both test were comparable, again with the notable exception of lead
- Cyclone hopper ash leachate samples for both tests had significantly higher trace element content than bottom ash leachate samples
- The test 2 (coal/PET fuel) cyclone hopper ash leachate had consistently lower levels of most trace elements than the cyclone hopper ash leachate from test 1 (coal fuel)

The relatively poor implied accuracy of the SSMS analyses would not affect the first three conclusions, except for the lead exception noted. However, high lead levels in the SASS particulate were quantitated using AAS analysis, which did meet appropriate QA objectives for precision and accuracy. The fourth conclusion was based on factor of 3 or greater differences in noted concentrations. The fact that this was consistently observed and consistent with bioassay test results suggests that it also remains a valid conclusion not significantly affected by a failure to attain uniform factor of 3 apparent accuracy in SSMS analyses.

5.2 ULTIMATE ANALYSIS PRECISION

Duplicate samples of the cyclone hopper ash sample for test 1 (coal fuel) were submitted to the laboratory retained for proximate, ultimate, and heating value analyses. Results of the duplicate ultimate analyses are summarized in Table 5-5. Although there is no project QA goal for this analysis, results in Table 5-5 show that average measurement precision was better than 5 percent, all determinations had individual precision of better than 20 percent, and, in fact, all determination except one had individual precision of better than 5 percent.

TABLE 5-5. RESULTS OF DUPLICATE TEST 1 CYCLONE HOPPER ASH ULTIMATE ANALYSES

	Concentration (percent by weight, dry basis unless noted)		Relative standard deviation (percent)
Component	Sample 1	Sample 2	
Carbon	30.90	30.90	0
Hydrogen	1.40	1.07	18.9
Nitrogen	1.00	1.06	4.1
Sulfur	4.50	4.60	1.6
Chloride	51.06	48.39	3.8
Ash	0.20	0.19	3.6
Moisture[a]	8.73	8.97	1.9
		Average	4.8

[a] As received

5.3 ORGANIC ANALYSIS PRECISION

Two aliquots of the SASS train organic sorbent module extract were subjected to TCO and to GC/MS analysis for the semivolatile organic priority pollutants. Results of the duplicate analyses are given in Table 5-6. As noted, the precision of the TCO analysis was 16 percent, which just fails the project QA objective of 10 percent (Ref. 5-2). This failure has little impact on test conclusions. These conclusions are that total organic emissions from the boiler were comparable for both tests and composed mostly

TABLE 5-6. RESULTS OF DUPLICATE TEST 2 ORGANIC SORBENT MODULE EXTRACT ORGANIC ANALYSES

Component	Concentration (μg/train)		Relative standard deviation (percent)
	Aliquot 1	Aliquot 2	
Total chromatographable organics (TCO)	3.5	2.8	16
Semivolatile organic priority pollutants:			
Naphthalene	0.35	0.44	16
Phenol	0.45	0.54	13
Phenanthrene	0.07	0.08	9
Fluoranthene	0.05	0.06	13
Bis(2-ethylhexyl) phthalate	0.14	0.07	47
Diethyl phthalate	0.15	0.15	0
Average semivolatile organic priority pollutants			20

(about 90 percent) of nonvolatile (gravimetric) organic. Only gravimetric analyses were performed on ash samples.

Table 5-6 shows that the average precision of the GC/MS analysis was 20 percent, well within the project QA objective of 50 percent (Ref. 5-2). Individual compound measurement precision ranged from 0 to 47 percent, all within the QA goal. In fact all individual compound determinations except one (of six) had a precision of better than 20 percent.

5.4 METHOD 8 LABORATORY ANALYSIS ACCURACY

Two blind audit samples obtained from EPA's Environmental Monitoring and Support Laboratory (EMSL) were submitted along with the field Method 8 samples for laboratory analysis via barium-thorin titration. Results of the analyses of these samples are summarized in Table 5-7. As shown, laboratory analytical accuracy was within less than ±5 percent for all audit samples. In fact accuracy was within ±1 percent for two of the three samples analyzed.

TABLE 5-7. METHOD 8 AUDIT SAMPLE ANALYSIS RESULTS

	SO_2 concentration (mg/dscm)		
Lot 0282 Sample number	Reported	Actual from EMSL	Percent difference
4xxx	395.4	381.3	3.7
8xxx	2,345.4	2,325.9	0.8
9xxx	873.5	877.0	-0.4

REFERENCES FOR SECTION 5

5-1. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, NTIS PB293795, October 1978.

5-2. "Quality Assurance Plan for the Combustion Modification Environmental Assessment," prepared under EPA Contract No. 68-02-3188, September 10, 1982.

APPENDIX A

SAMPLING AND ANALYSIS METHODS

Emissions test equipment was provided by Acurex Corporation. Onsite equipment included a continuous monitoring system for emissions measurements of O_2, CO_2, and gaseous criteria pollutants; a combined EPA Method 5/8 train for particulate, SO_2, and SO_3 emissions; the SASS train for particulate mass and size distribution, trace element, and semivolatile and nonvolatile organic emissions; a VOST train for volatile organic emissions; a sampling train for HCl measurement; and gas grab sampling equipment for determining N_2O emissions by laboratory gas chromatography. The following sections summarize the sampling and analysis equipment and methods used in the field and laboratory.

A.1 CONTINUOUS MONITORING SYSTEM

Rack-mounted monitors and recorders located in a mobile emission laboratory were used for continuous measurement of O_2, CO_2, NO_x, CO, and total unburned hydrocarbon (TUHC). Figure A-1 illustrates the continuous flue gas extractive sampling system and monitors arrangement. Flue gas was drawn through an in-stack filter and a heated stainless steel probe to a gas conditioning and refrigeration system designed to remove water. An unheated line was then used to bring the conditioned gas to the monitors. Calibration gases were used to monitor and correct the drift in the instruments. The

1. *In situ* filter 0.6μ 99.999 percent efficient
2. Exhaust duct
3. 316 stainless steel probe
4. Four pass conditioner-dryer, 316 stainless steel internals
5. 3/8-inch unheated Teflon
6. Teflon-lined sample pump
7. 3/8-inch heated teflon
8. Rotameter
9. 1/4-inch Teflon tubing
10. Calibration gas manifold
11. Calibration gas selector valve
12. Calibration gas cylinders
13. Backpressure regulator

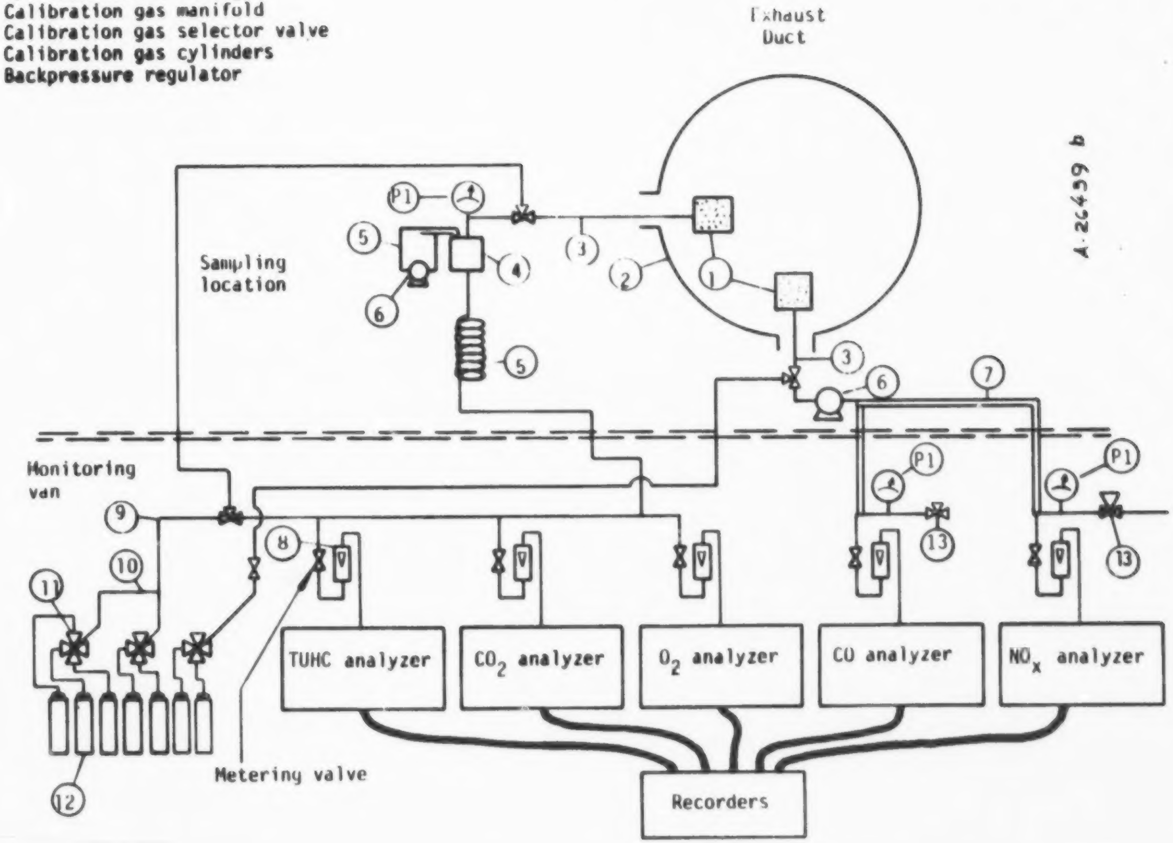

Exhaust
Duct
A-26459 b
Sampling
location
Monitoring
van
P1
1
2
3
4
5
6
7
8
9
10
11
12
13
TUHC analyzer
CO_2 analyzer
O_2 analyzer
CO analyzer
NO_x analyzer
Recorders
Metering valve

Figure A-1. Continuous monitoring system.

calibration gases follow the same path as the flue gas being monitored in both are conditioned at the stack prior to analysis. Table A-1 lists the instrumentation constituting the continuous monitoring and flue gas extractive sampling system used in this test program.

A.2 PARTICULATE AND SULFUR OXIDE EMISSIONS

Particulate mass emissions were measured in accordance with EPA Reference Method 5 and SO_2 and SO_3 emissions were measured in accordance with EPA Reference Method 8. A combined Method 5/8 train employing the Acurex High Volume Stack Sampler (HVSS), illustrated schematically in Figure A-2, was used in this program. A glass-lined stainless-steel probe was used to isokinetically extract the gas sample from the stack. Particulate was removed by a heated 142 mm (5.6 in.) diameter glass fiber filter. Both the filter and the sampling probes were maintained at 120°C (250°F) as specified by Method 5.

The impinger train consisted of four glass impingers with a fritted glass filter placed between the first and second impingers as specified by Method 8. The first impinger contained 100 ml of 80 percent isopropanol (20 percent water); the second and third impingers contained 100 ml of 3 percent H_2O_2 in water; and the fourth impinger contained 200g of silica gel.

Solid particulate emissions were determined by gravimetric analysis of the probe wash and the heated glass fiber filter.

SO_2 and SO_3 emissions were measured by titration of the impinger solutions per EPA Method 8. Sulfuric acid mist and any vapor phase SO_3 is trapped in the isopropanol impinger with the backup filter trapping any

TABLE A-1. CONTINUOUS MONITORING EQUIPMENT IN THE MOBILE LABORATORY

Instrument	Principle of operation	Manufacturer	Instrument model	Range
NO NO_x	Chemiluminescence	Thermo Electron	10 AR	0-100 ppm 0-500 ppm 0-1,000 ppm 0-5,000 ppm
CO	Nondispersive infrared (NDIR)	ANARAD	500R	0-1,000 ppm
TUHC	Flame ionization detector	Beckman	400	0-10 ppm 0-100 ppm 0-1000 ppm
CO_2	Nondispersive infrared (NDIR)	ANARAD	AR500	0-20 percent
O_2	Fuel cell	Teledyne		0-5 percent 0-25 percent
Sample gas conditioner	Refrigerant dryer-condenser	Hankinson	E-4G-SS	10 scfm
Strip chart recorder	Dual pen analog	Linear	400	0-10 mV 0-100 mV 0-1V 0-10V

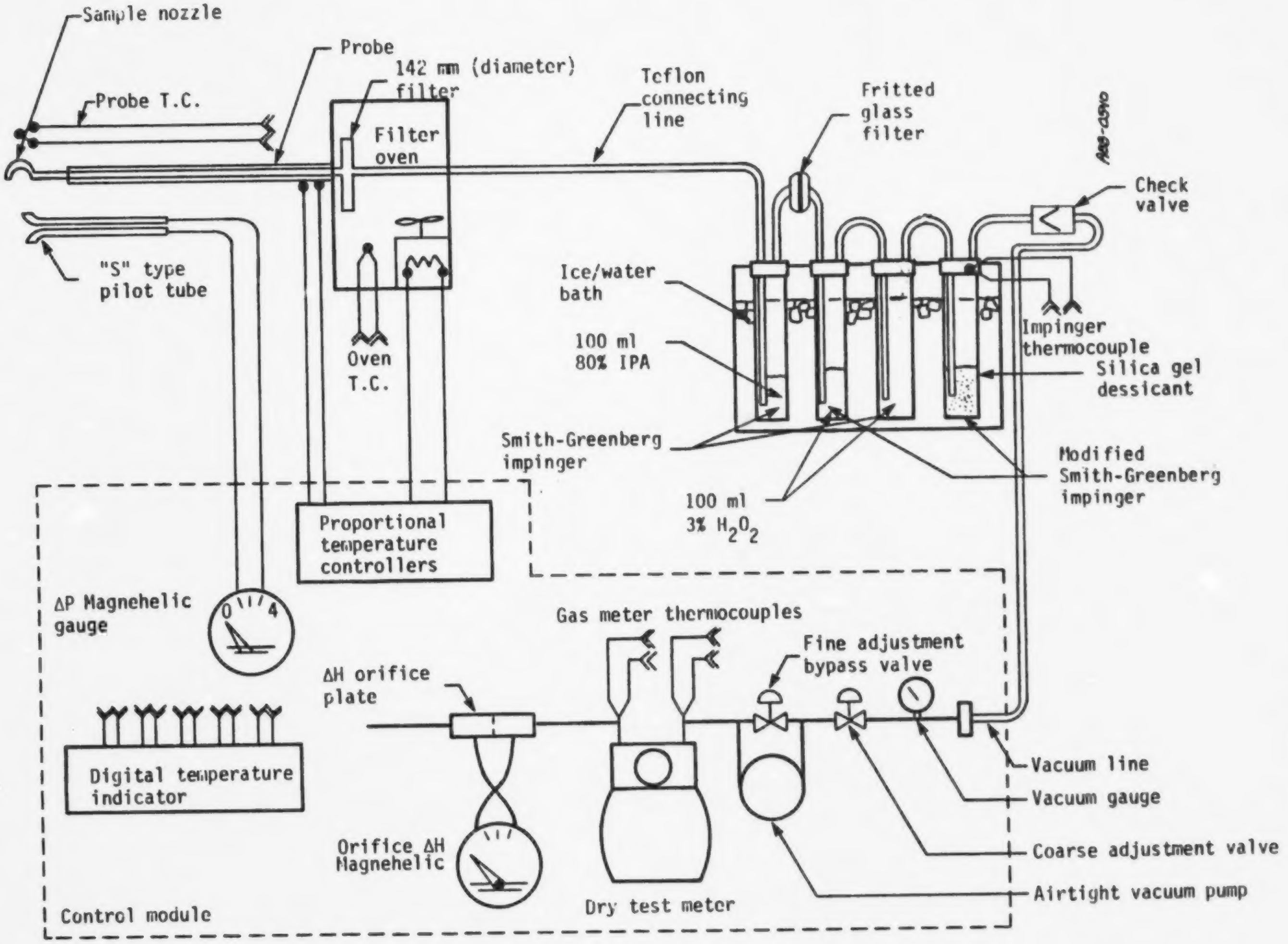

Sample nozzle
Probe T.C.
Probe
142 mm (diameter) filter
Filter oven
Teflon connecting line
Fritted glass filter
A88-0590
Check valve
"S" type pilot tube
Oven T.C.
Ice/water bath
100 ml 80% IPA
Impinger thermocouple
Silica gel dessicant
Smith-Greenberg impinger
Modified Smith-Greenberg impinger
100 ml 3% H_2O_2
Proportional temperature controllers
ΔP Magnehelic gauge
0
4
Gas meter thermocouples
Fine adjustment bypass valve
ΔH orifice plate
Digital temperature indicator
Vacuum line
Vacuum gauge
Coarse adjustment valve
Airtight vacuum pump
Orifice ΔH Magnehelic
Dry test meter
Control module

Figure A-2. Schematic of particulate and SO_x sampling train (EPA Method 5 and 8).

carryover mist. SO_2 is absorbed in the H_2O_2 impingers. After completion of a test, the filter was rinsed with isopropanol and the rinse solution added to the isopropanol impinger solution. Absorbed SO_3 in the isopropanol and SO_2 in the H_2O_2 were determined separately by barium-thorin titration.

A.3 TRACE ELEMENT AND ORGANIC EMISSIONS

Emissions of inorganic trace elements and organic compounds were sampled with the source assessment sampling system (SASS). Designed for Level 1 environmental assessment (Reference A-1), the SASS collects large quantities of gas and solid samples required for subsequent analyses of inorganic and organic emissions as well as particle size measurement.

The SASS, illustrated in Figure A-3, is generally similar to the system utilized for total particulate mass emission tests (HVSS) with the exception of:

- Particulate cyclones heated in the oven with the filter to 230°C (450°F)
- The addition of a gas cooler and organic sampling module
- The addition of necessary vacuum pumps

Schematics outlining the sampling and analytical procedures using the SASS equipment are presented in Figures A-4 and A-5. The following paragraphs briefly describe analytical procedures used in measuring stack outlet trace elements and organic emissions.

Inorganic analyses of solid and liquid samples from the SASS train were performed with spark source mass spectroscopy (SSMS) for most of the trace elements. Atomic absorption spectrometry (AAS) was used for analyses of volatile mercury (Hg), antimony (Sb), and arsenic (As) and for backup analyses for those elements identified as major components by SSMS. Other

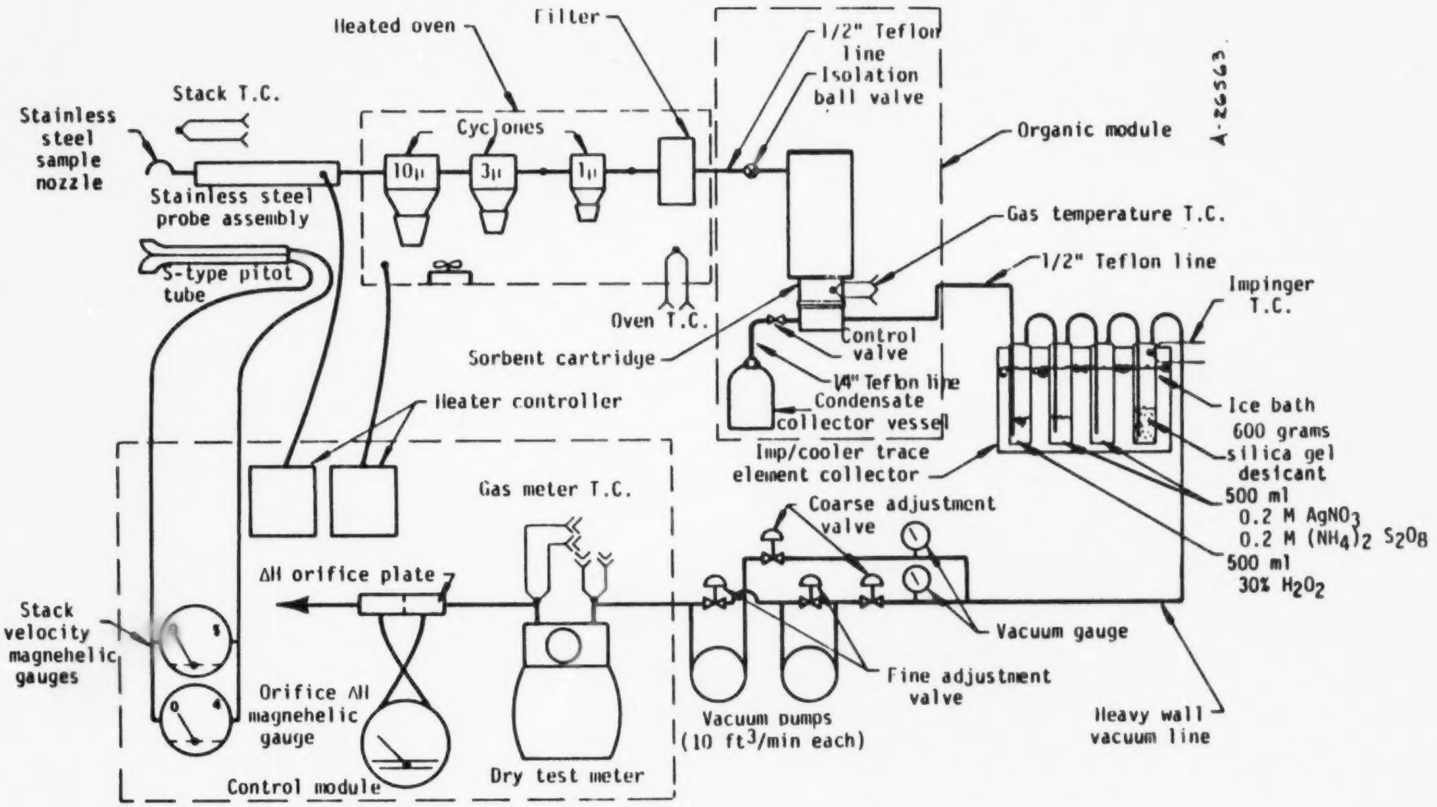
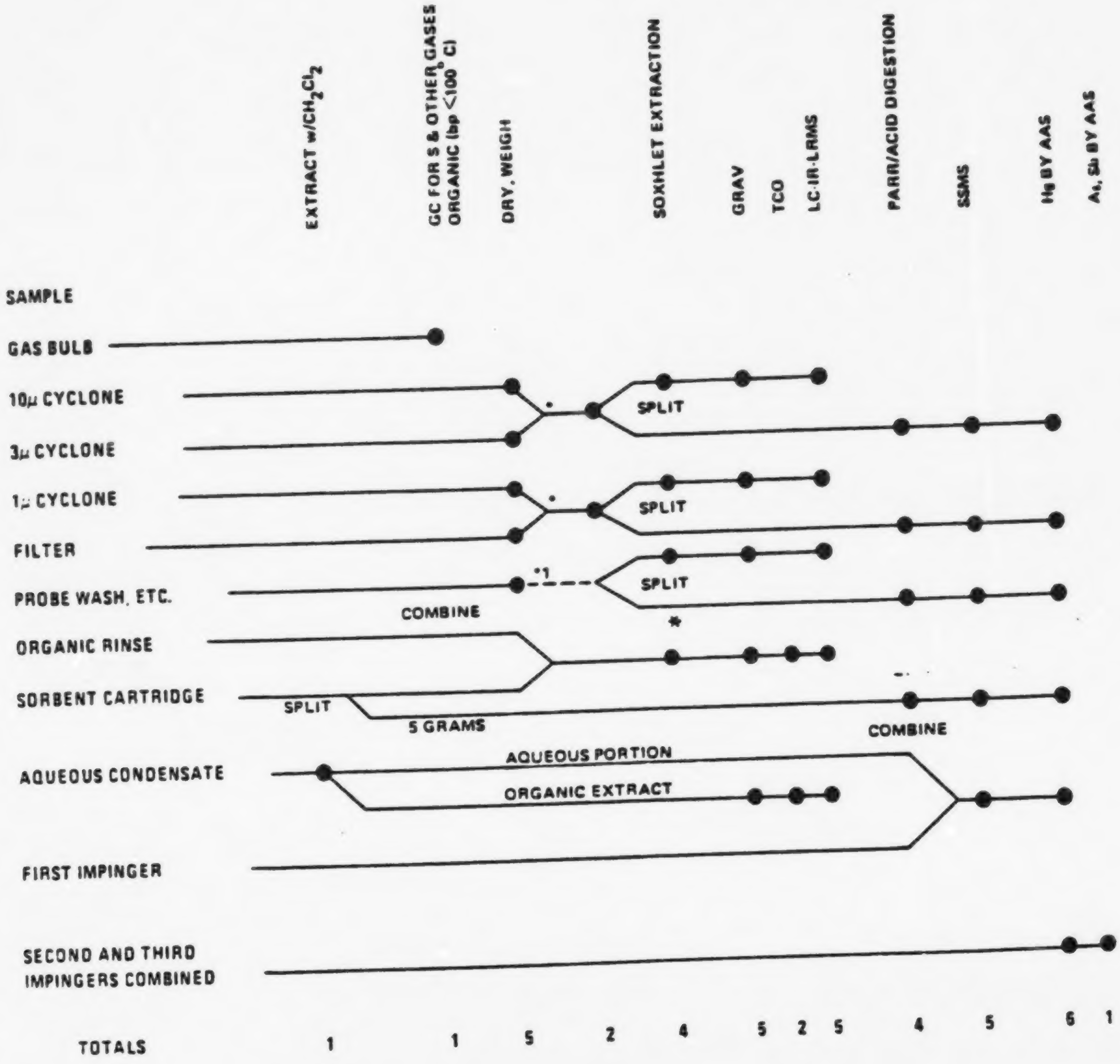

Stainless steel sample nozzle
Stack T.C.
Stainless steel probe assembly
S-type pitot tube
Heated oven
Cyclones
10μ
3μ
1μ
Filter
Oven T.C.
1/2" Teflon line
Isolation ball valve
Organic module
A-26563
Gas temperature T.C.
Sorbent cartridge
Control valve
1/4" Teflon line
Condensate collector vessel
1/2" Teflon line
Impinger T.C.
Ice bath
600 grams silica gel desicant
500 ml 0.2 M AgNO$_3$ 0.2 M (NH$_4$)$_2$ S$_2$O$_8$
500 ml 30% H$_2$O$_2$
Imp/cooler trace element collector
Heater controller
Gas meter T.C.
Coarse adjustment valve
Vacuum gauge
Fine adjustment valve
Heavy wall vacuum line
Vacuum pumps (10 ft^3/min each)
ΔH orifice plate
Stack velocity ΔP magnehelic gauges
Orifice ΔH magnehelic gauge
Dry test meter
Control module

Figure A-3. SASS train schematic.


EXTRACT w/CH2Cl2
GC FOR S & OTHER GASES ORGANIC (bp <100° C)
DRY, WEIGH
SOXHLET EXTRACTION
GRAV
TCO
LC-IR-LRMS
PARR/ACID DIGESTION
SSMS
Hg BY AAS
As, Sb BY AAS
SAMPLE
GAS BULB
10μ CYCLONE
3μ CYCLONE
1μ CYCLONE
FILTER
PROBE WASH, ETC.
ORGANIC RINSE
SORBENT CARTRIDGE
AQUEOUS CONDENSATE
FIRST IMPINGER
SECOND AND THIRD IMPINGERS COMBINED
SPLIT
SPLIT
SPLIT
*1
COMBINE
SPLIT
5 GRAMS
COMBINE
AQUEOUS PORTION
ORGANIC EXTRACT
TOTALS
1
1
5
2
4
5
2
5
4
5
6
1

* If required, sample should be set aside for biological analysis at this point.

[1] This step is required to define the total mass of particulate catch. If the sample exceeds 10% of the total cyclone and filter sample weight proceed to analysis. If the sample is less than 10% of the catch, hold in reserve.

4

Figure A-4. Flue gas analysis protocol for SASS samples.

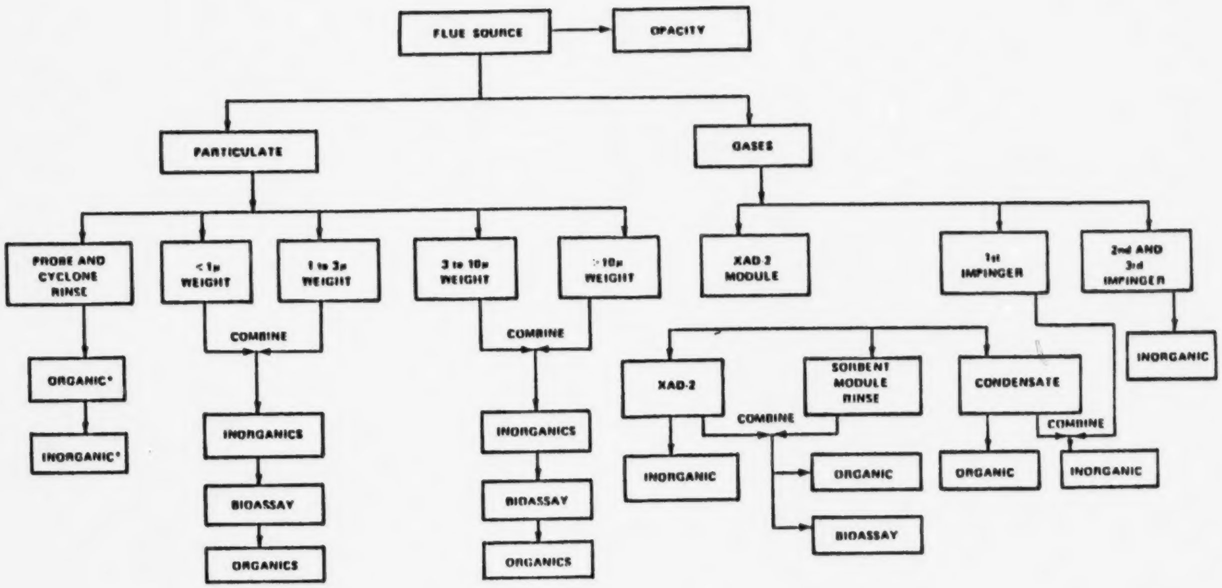

FLUE SOURCE
OPACITY
PARTICULATE
GASES
PROBE AND CYCLONE RINSE
<1μ WEIGHT
1 to 3μ WEIGHT
3 to 10μ WEIGHT
>10μ WEIGHT
XAD-2 MODULE
1st IMPINGER
2nd AND 3rd IMPINGER
COMBINE
COMBINE
ORGANIC*
INORGANIC*
INORGANICS
BIOASSAY
ORGANICS
INORGANICS
BIOASSAY
ORGANICS
XAD-2
SORBENT MODULE RINSE
CONDENSATE
INORGANIC
COMBINE
COMBINE
INORGANIC
ORGANIC
BIOASSAY
ORGANIC
INORGANIC

Figure A-5. Flue gas analysis protocol.

major component backup methods used were specific ion electrode for chlorine and fluorine, colorimetric for boron and phosphorus, and either turbidimetric or x-ray fluorescence for sulfur.

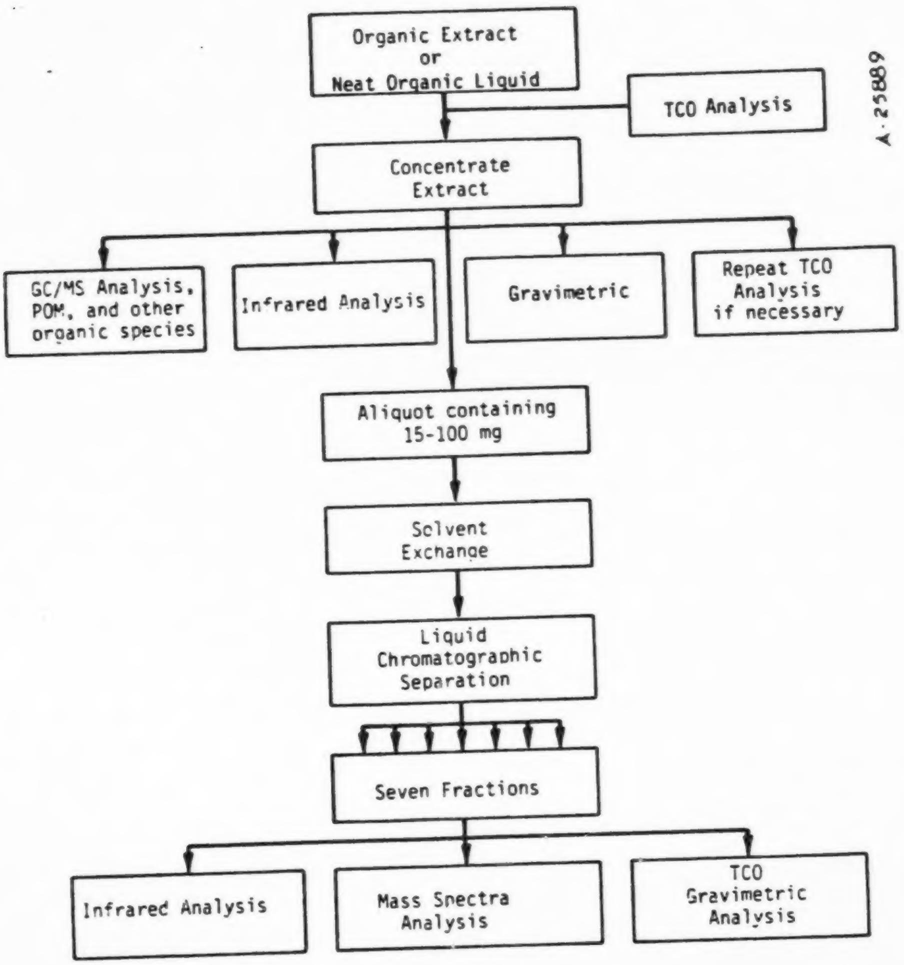
Quantitative information on total organic emissions was obtained by gas chromatography for total chromatographable organics (TCO) and by gravimetry (GRAV) of particulate, sorbent module (XAD-2), and condensate trap organic extracts. Infrared spectroscopy (IR) of extract sample GRAV residues was used for identification or organic functional groups. Gas chromatography/mass spectrometry (GC/MS) was used to quantitate the semivolatile organic priority pollutant species in extract samples. This class contains several of the polynuclear aromatic hydrocarbon (PAH) compounds of interest from combustion sources. Figure A-6 illustrates the organic analysis methodology followed.

Total sample extracts containing total (TCO + GRAV) organic content of greater than 15 mg were further analyzed via liquid column (LC) chromatography. This analysis separates the organic components into seven polarity fractions. TCO, GRAV, and IR analyses were performed on each eluted fraction.

Specifics of the Level 1 methodology followed (with extension) are detailed in Ref. A-1.

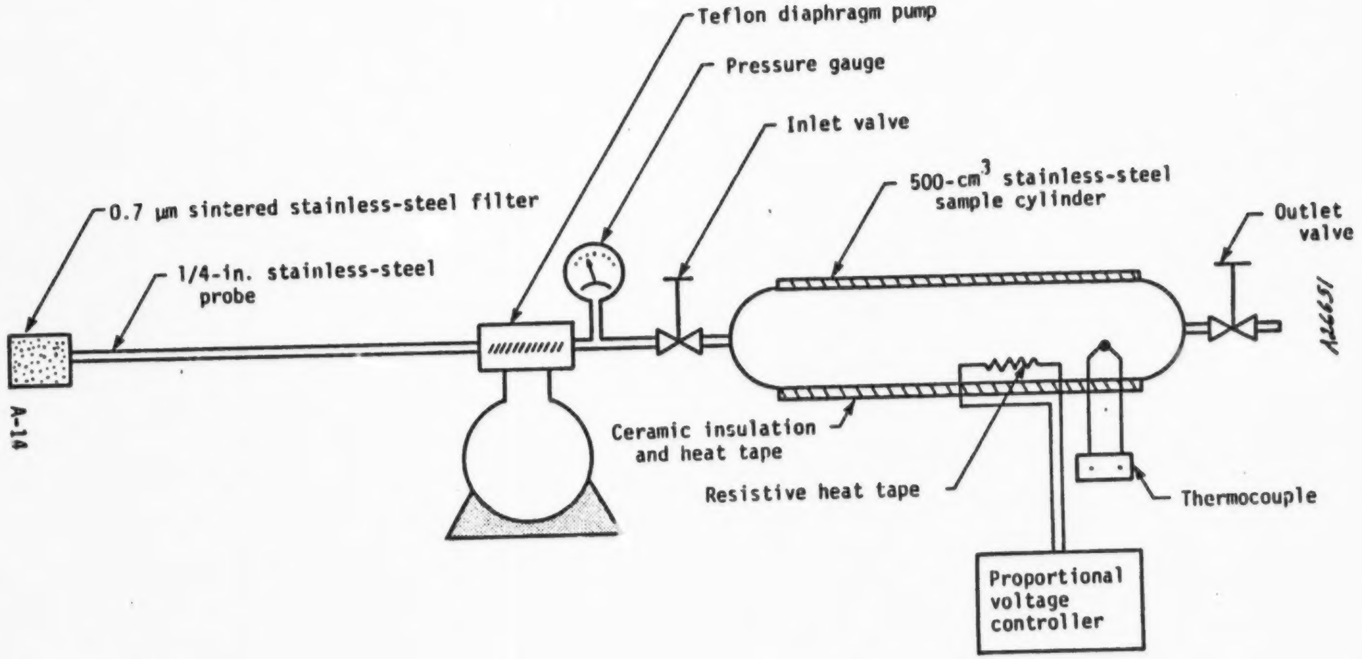
A.4 N_2O EMISSIONS

Stack gas samples for laboratory analysis for N_2O were collected by a grab sampling procedure using the apparatus illustrated in Figure A-7. The equipment consisted of a heated, 0.64-cm (1/4-in.) OD pyrex-lined, stainless-steel probe fitted with a 0.7-μm sintered stainless steel filter at the probe inlet. The outlet of the probe was directly attached to a



Organic Extract or Neat Organic Liquid
TCO Analysis
Concentrate Extract
GC/MS Analysis, POM, and other organic species
Infrared Analysis
Gravimetric
Repeat TCO Analysis if necessary
Aliquot containing 15-100 mg
Solvent Exchange
Liquid Chromatographic Separation
Seven Fractions
Infrared Analysis
Mass Spectra Analysis
TCO Gravimetric Analysis
A-25889

Figure A-6. Organic analysis methodology.


Teflon diaphragm pump
Pressure gauge
Inlet valve
500-cm^3 stainless-steel sample cylinder
Outlet valve
0.7 μm sintered stainless-steel filter
1/4-in. stainless-steel probe
A-14
Ceramic insulation and heat tape
Resistive heat tape
Thermocouple
Proportional voltage controller

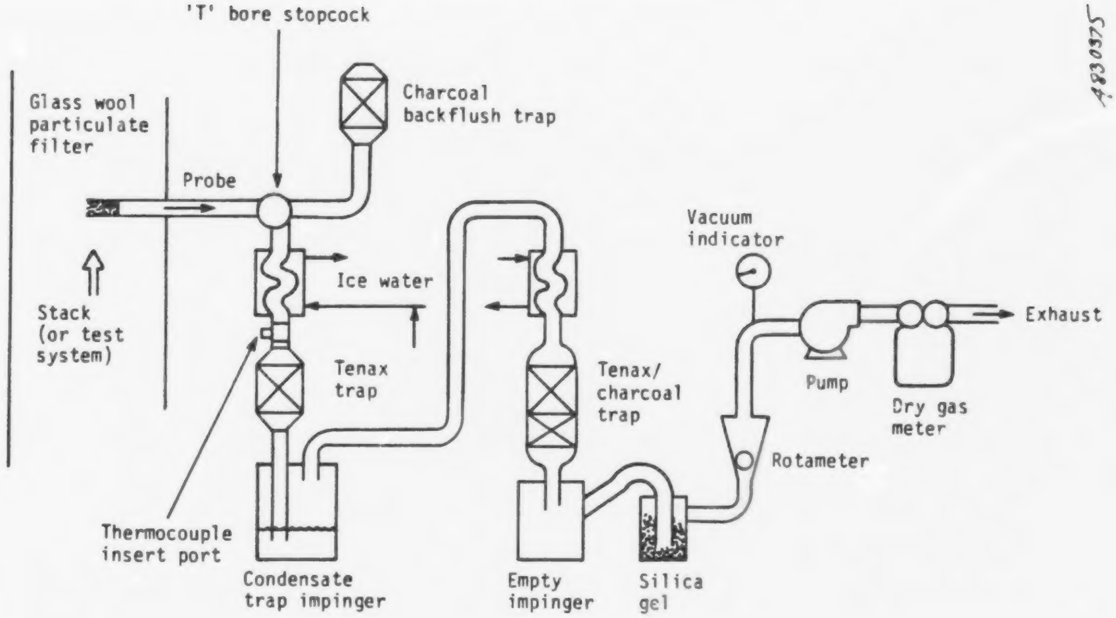
A16651

Figure A-7. N_2O sampling system.

diaphragm vacuum pump which was in turn attached to a 500-ml heated stainless steel sampling cylinder. The sampling cylinder was insulated with heat tape powered by a varying voltage controller. The heated jacket kept the sample gas above the dew point to minimize sample loss due to water condensation. Prior to sampling, the gas cylinder was purged with stack gas for 3 min and then sealed. The trapped flue gas was then transported to the laboratory for analysis. For the analysis, each sample cylinder was externally heated to 120°C (250°F), then a 1-ml sample was withdrawn with a gas-tight syringe for injection into a gas chromatograph. The analytical equipment consisted of a gas chromatograph equipped with a ^{63}Ni electron capture detector and a 5.5m (18-ft) stainless-steel column packed for 3.7m (12-ft) with Poropak R 80/100 mesh and 1.8m (6-ft) with Poropak Super Q. The injector temperature was kept at 120°C, the detector at 350°C, and the column temperature at 39°C. Elution time for N_2O was approximately 7.5 min.

A.5 VOLATILE ORGANIC EMISSIONS

A volatile organic sampling train (VOST), shown schematically in Figure A-8, was used to measure the low molecular weight volatile organic compounds (boiling points $\leq$110°C) in the flue gas according to the EPA protocol (Ref. A-2). The train consists of two organic sorbent traps connected in series. The first trap contained ~1.6g of the porous polymer Tenax-GC; 35/60 mesh. The second trap contained ~1.0g each of Tenax-GC and petroleum-based charcoal. Prior to their use in the field, each trap was conditioned to remove organic compounds. Conditioning consisted of baking each trap at 190°C with a N_2 purge for an 8-hour period. The traps were then desorbed at 190°C directly into a GC/FID. If a trap showed no contaminant


'T' bore stopcock
Charcoal backflush trap
Glass wool particulate filter
Probe
Stack (or test system)
Ice water
Vacuum indicator
Exhaust
Pump
Dry gas meter
Tenax trap
Tenax/ charcoal trap
Rotameter
Thermocouple insert port
Condensate trap impinger
Empty impinger
Silica gel

A830375

Figure A-8. Schematic of volatile organic sampling train (VOST).

peaks greater than 20 ng as benzene or toluene, it was sealed at each end with compression fittings, and considered ready for sampling.

Before the field testing, the entire system was leak-checked at ~15 to 20-in. of vacuum. A leakage rate of 0.05 liter/min was considered acceptable. Ambient air was drawn through a charcoal-filled tube to prevent organic contamination while bringing the system back to ambient pressure.

One pair of sample traps and a field blank pair were obtained for the test program. A total sample volume of 20 liters was taken over a 40-min period (0.5 l/min). Upon completion of the test, the sample traps were removed from the train, and sealed. All traps were analyzed by GC/MS according to the EPA VOST protocol (Ref. A-2). Each pair of traps used was thermally desorbed and analyzed for the EPA Method 624 (volatile) priority pollutants.

A.6 HCl SAMPLING AND ANALYSIS

HCl was measured at the stack using a separate sampling train. The train was similar to an EPA Method 6 train except that impinger solutions were caustic based (0.1N NaOH). The concentrations of chloride ion in impinger solutions were determined in the laboratory using a wet chemical method (argentometric titration).

A.7 FUEL AND ASH SAMPLING AND ANALYSIS

Fuel samples were taken after each test from the fuel bin filled at the beginning of each test day. Ash samples were collected from the boiler and the cyclone collector hopper (a 55-gal drum) after each test.

Fuel samples were subjected to proximate, ultimate, and heating value analysis, as well as trace element analyses using the methods noted above for SASS train samples. Ash samples were subjected to ultimate and trace element analyses. In addition, aqueous leachates of ash samples were prepared according to Level 1 protocol and analyzed for trace element content using the methods noted above for SASS train samples, and for leachable anions using ion chromatography.

REFERENCES FOR APPENDIX A

A-1. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, NTIS PB293795, October 1978.

A-2. "Protocol for the Collection and Analysis of Volatile POHC's Using VOST," EPA-600/8-84-007, NTIS PB84-170042 March 1984.

APPENDIX B

TRACE ELEMENT CONCENTRATIONS

The following tables present sample trace element analysis results and trace element discharge stream concentrations. The tables labeled "input data" give element analysis results (μg/g or μg/ml) for each sample analyzed. The composition of the fuels, bottom ashes and their aqueous leachates, cyclone hopper ashes and their aqueous leachates, and all SASS train samples (10 + 3 μm particulate, filter + 1 μm particulate, XAD-2 resin, first impinger, and second and third impingers) are noted. Leachable anion concentrations in leachates are also given.

The tables labeled "mass/flue volume" give the calculated flue gas concentrations (μg/dscm) of each element corresponding to each SASS train sample, and the SASS train sum (labeled "stack exhaust").

The tables labeled "mass/heat input" give element flowrates in ng/J heat input. The tables labeled "mass/time" give corresponding flowrates in μg/s. Element flowrates in the fuel input and all discharge streams (bottom ash, cyclone hopper ash, and flue gas) as well as each component of the flue gas SASS train sample are noted.

The final table, labeled "boiler mass balance," summarizes the total input and output for each element and notes the ratio of the two as a measure of mass balance closure.

Symbols appearing in the tables include:

DSCM	Dry standard cubic meter at 1 atm and 20°C
MCG	Microgram
PPM	Part per million by weight
<	Less than
>	Greater than
N	Element not analyzed

Trace elements having concentrations less than the detectable limit or having a blank value greater than the sample value were given an arbitrary concentration of zero. Values in the form A < x < B were determined by letting elements reported as less than some concentration be represented by a concentration of zero for the low value and the reported (less than) concentration as the high value.

Detectability limits for the various SASS, liquid, and solid stream samples were the following:

- 10 + 3 μm particulate -- 0.2 μg/g
- Filter + 1 μm paticulate -- 0.1 μg/g
- XAD-2 -- 0.01 to 0.2 μg/g
- Impinger solution -- 0.002 to 0.006 μg/ml
- Fuel -- 0.1 to 0.2 μg/g
- Bottom ash and cyclone -- 0.1 μg/g
- Ash leachates -- 0.001 to 0.002 μg/ml

The data inputs to the computer code for calculation of trace element flowrates were the following:

Test 1 (coal)

- Coal flowrate = 30 g/s
- Heating value of coal = 31,267 kJ/kg
- Gas volume sampled by SASS = 27.389 dscm
- Calculated flue gas flowrate = 0.621 dscm
- Bottom ash flowrate = 3.92 g/s
- Cyclone hopper ash flowrate = 0.12 g/s
- SASS 10 + 3 μm cyclone catch = 0.4750g
- SASS 1 μm cyclone + filter catch = 0.4166g
- XAD-2 weight = 130g
- SASS impinger 1 final volume = 610 ml
- SASS impingers 2 + 3 final volume = 1,150 ml

Test 2 (coal/PET)

- Coal/PET flowrate = 36 g/s
- Heating value of fuel = 31,044 kJ/kg
- Gas volume sampled by SASS = 24.971 dscm
- Calculated flue gas flowrate = 0.671 dscm/s
- Bottom ash flowrate = 2.42 g/s
- Cyclone hopper ash flowrate = 0.08 g/s
- SASS 10 + 3μm cyclone catch = 0.5840g
- SASS 1 μm cyclone + filter catch* = 0.5760g
- XAD-2 weight = 130g
- SASS impinger 1 final volume = 1,335 ml
- SASS impingers 2 + 3 final volume = 1,110 ml

---

*Estimated 1 μm cyclone weight for test 2 by analogy to test 1. The 1 μm cyclone ash for test 2 was destroyed during transit.

At standard conditions (20°C (68°F) and 1 atm), one gram molecular weight of an ideal gas occupies 24.04 liters.

INPUT DATA

ROCK OF AGES
TEST 1 - COAL ONLY
PPM

ELEMENT	FUEL: COAL	BOTTOM ASH	CYCLONE ASH	BOTTOM ASH LEACHATE	CYCLONE ASH LEACHATE
ALUMINUM	.119E+05	.129E+06	.562E+05	.500E+00	.150E+04
ANTIMONY	<.100E+01	.400E+01	.600E+01	<.400E-02	.150E+00
ARSENIC	.110E+02	.400E+01	.520E+02	.300E-01	.410E+01
BARIUM	.100E+03	.350E+03	.130E+03	.600E-01	.210E+01
BERYLLIUM	.900E+01	.220E+02	.700E+01	.000E+00	.320E+00
BISMUTH	.000E+00	.000E+00	.400E+00	.000E+00	.500E-02
BORON	.300E+02	.310E+02	.110E+03	.200E+00	.180E+01
BROMINE	.210E+02	.400E+01	.490E+02	.300E-01	.510E+00
CADMIUM	.100E+01	.400E+00	.400E+00	.000E+00	.170E+00
CALCIUM	.193E+04	.119E+05	.670E+04	.110E+03	.180E+01
CERIUM	.180E+02	.220E+02	.400E+01	.100E-02	.850E+00
CESIUM	.500E+00	.200E+01	.400E+00	.000E+00	.500E-01
CHLORIDE	.000E+00	.000E+00	.000E+00	.250E+01	.300E+03
CHLORINE	.200E+04	.980E+02	.250E+03	.500E+00	.660E+01
CHROMIUM	.120E+03	.500E+02	.510E+02	.200E-01	.370E+01
COBALT	.800E+01	.220E+02	.600E+01	<.100E-02	.740E+01
COPPER	.140E+02	.180E+02	.340E+02	.100E-01	.180E+02
DYSPROSIUM	.000E+00	.300E+01	.100E+01	.000E+00	.630E+00
ERBIUM	.000E+00	.200E+01	.500E+00	.000E+00	.300E+00
EUROPIUM	.300E+00	.200E+01	.400E+00	.000E+00	.900E-01
FLUORIDE	.000E+00	.000E+00	.000E+00	.250E+00	.460E+00
FLUORINE	.830E+03	<.100E+03	.260E+03	.400E+01	.420E+02
GADOLINIUM	.700E+00	.300E+01	.900E+00	.000E+00	.230E+00
GALLIUM	.160E+02	.100E+02	.190E+02	.100E-01	.650E+01
GERMANIUM	.100E+01	.100E+01	.400E+01	.200E-02	.220E+00
HAFNIUM	.000E+00	.300E+01	.300E+00	.000E+00	.300E-01
HOLMIUM	.000E+00	.200E+01	.700E+00	.000E+00	.400E+00
IODINE	.100E+01	.200E+01	.300E+01	.200E-02	.800E-02
IRON	.340E+04	.475E+05	.952E+05	.600E-01	.110E+04
LANTHANUM	.250E+02	.300E+02	.600E+01	.000E+00	.120E+01
LEAD	.300E+01	.900E+01	.140E+02	<.400E-02	.270E+00
LITHIUM	.740E+02	.120E+03	.790E+02	.300E+01	.470E+01
LUTETIUM	.000E+00	.300E+00	<.100E+00	.000E+00	.300E-01
MAGNESIUM	.480E+03	.460E+04	.150E+04	.470E+01	.110E+03
MANGANESE	.800E+01	.130E+02	.110E+02	.200E-02	.240E+02
MERCURY	.900E-01	<.100E-01	.780E+00	.200E-02	<.100E-02
MOLYBDENUM	.270E+02	.600E+01	.800E+01	.100E+00	.220E+00
NEODYMIUM	.700E+01	.140E+02	.300E+01	.000E+00	.720E+00
NICKEL	.200E+01	.160E+03	.790E+02	.100E-01	.400E+01
NIOBIUM	.120E+02	.900E+01	.400E+01	<.100E-02	.190E+00
NITRATE	.000E+00	.000E+00	.000E+00	<.100E+01	<.100E+02
NITRITE	.000E+00	.000E+00	.000E+00	<.100E+01	<.100E+02
PHOSPHATE	.000E+00	.000E+00	.000E+00	<.100E+01	<.100E+02
PHOSPHORUS	.100E+03	.740E+03	.270E+04	.100E+00	.200E-01
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

ROCK OF AGES
TEST 1 - COAL ONLY
PPM

INPUT DATA

ELEMENT	FUEL: COAL	BOTTOM ASH	CYCLONE ASH	BOTTOM ASH LEACHATE	CYCLONE ASH LEACHATE
POTASSIUM	.116E+04	.124E+05	.510E+04	.730E+01	.140E+03
PRASEODYMIUM	.300E+01	.700E+01	.100E+01	.000E+00	.340E+00
RUBIDIUM	.500E+01	.800E+01	.200E+01	.800E-02	.630E+00
SAMARIUM	.100E+01	.700E+01	.300E+01	.000E+00	.760E+00
SCANDIUM	.350E+02	.300E+02	.260E+02	<.100E-02	.850E+00
SELENIUM	.130E+03	.130E+02	.170E+03	.100E+00	.800E+00
SILICON	.187E+05	.212E+06	.820E+05	.400E+01	.890E+02
SILVER	.000E+00	.500E+00	.500E+00	<.200E-02	.800E-02
SODIUM	.520E+03	.560E+04	.260E+04	>.100E+02	.170E+03
STRONTIUM	.110E+03	.210E+03	.900E+02	.600E+00	.240E+02
SULFATE	.000E+00	.000E+00	.000E+00	.300E+03	.190E+05
SULFITE	.000E+00	.000E+00	.000E+00	.200E+02	.500E+04
SULFUR	.100E+05	.320E+03	.405E+05	.110E+03	.153E+05
TANTALUM	.000E+00	.900E+00	.400E+00	.000E+00	.300E-01
TELLURIUM	.000E+00	<.200E+00	.400E+00	.000E+00	.100E-01
TERBIUM	.200E+00	.800E+00	.200E+00	.000E+00	.600E-01
THALLIUM	.000E+00	.100E+01	.200E+01	.000E+00	.210E+00
THORIUM	.500E+01	.140E+02	.200E+01	.000E+00	.310E+00
THULIUM	.000E+00	.200E+00	.200E+00	.000E+00	.400E-01
TIN	.500E+00	.800E+00	.100E+01	.000E+00	.200E-01
TITANIUM	.540E+03	.680E+04	.350E+04	.300E+00	.440E+01
TUNGSTEN	.000E+00	.100E+01	.500E+00	.000E+00	.300E-01
URANIUM	.200E+01	.900E+01	.200E+01	.000E+00	.690E+00
VANADIUM	.400E+02	.440E+02	.850E+02	.200E-01	.740E+01
YTTERBIUM	.000E+00	.100E+01	.500E+00	.000E+00	.270E+00
YTTRIUM	.100E+02	.110E+02	.500E+01	.100E-02	.120E+01
ZINC	.530E+02	.110E+02	.370E+02	.300E-01	.440E+02
ZIRCONIUM	.310E+02	.340E+02	.800E+01	.300E-02	.950E+00

INPUT DATA

ROCK OF AGES
TEST 1 - COAL ONLY
PPM

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	.758E+05	.539E+05	.250E+01	.100E+00	N.000E+00
ANTIMONY	.150E+03	.510E+02	.000E+00	.000E+00	.200E-02
ARSENIC	.490E+03	.550E+03	.600E-01	<.200E-02	.000E+00
BARIUM	.190E+04	.940E+03	.500E+00	.270E+00	N.000E+00
BERYLLIUM	.310E+02	.290E+02	.000E+00	.000E+00	N.000E+00
BISMUTH	.600E+01	.200E+02	.000E+00	.000E+00	N.000E+00
BORON	.230E+03	>.100E+04	.300E-01	.500E-02	N.000E+00
BROMINE	.220E+03	.250E+03	.200E+00	.000E+00	N.000E+00
CADMIUM	.140E+02	.770E+02	.000E+00	.500E-01	N.000E+00
CALCIUM	.132E+05	.111E+06	.000E+00	.800E+00	N.000E+00
CERIUM	.150E+03	.610E+02	.000E+00	.000E+00	N.000E+00
CESIUM	.110E+02	.400E+01	.200E+00	.000E+00	N.000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.850E+03	.470E+03	.700E+01	.000E+00	N.000E+00
CHROMIUM	.400E+02	.150E+03	.700E+00	.170E+00	N.000E+00
COBALT	.640E+02	.100E+03	.800E-01	.000E+00	N.000E+00
COPPER	.722E+03	.440E+03	.300E+00	.496E+00	N.000E+00
DYSPROSIUM	.900E+01	.300E+01	.000E+00	.000E+00	N.000E+00
ERBIUM	.400E+01	.100E+01	.000E+00	.000E+00	N.000E+00
EUROPIUM	.300E+01	.300E+01	.000E+00	.000E+00	N.000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.880E+03	>.100E+04	.900E+01	.100E+00	N.000E+00
GADOLINIUM	.600E+01	.400E+01	.000E+00	.000E+00	N.000E+00
GALLIUM	.830E+03	.350E+03	.000E+00	.530E-01	N.000E+00
GERMANIUM	.560E+02	.390E+02	<.600E-01	.000E+00	N.000E+00
HAFNIUM	.200E+01	.100E+01	.000E+00	.000E+00	N.000E+00
HOLMIUM	.600E+01	.200E+01	.000E+00	.000E+00	N.000E+00
IODINE	.290E+02	.600E+01	.200E-01	.000E+00	N.000E+00
IRON	.108E+06	.821E+05	.110E+02	.300E+00	N.000E+00
LANTHANUM	.870E+02	.610E+02	.000E+00	.000E+00	N.000E+00
LEAD	.460E+03	.600E+03	.000E+00	.600E+00	N.000E+00
LITHIUM	.950E+03	>.370E+03	.700E+00	.460E-01	N.000E+00
LUTETIUM	.400E+00	.300E+00	.000E+00	.000E+00	.000E+00
MAGNESIUM	.430E+04	.154E+05	.160E+02	.370E+01	N.000E+00
MANGANESE	.900E+03	.670E+02	.300E+00	.300E-01	N.000E+00
MERCURY	.500E+01	.900E-01	.200E+00	.100E-02	.700E-02
MOLYBDENUM	.840E+02	.650E+02	.300E+00	.000E+00	N.000E+00
NEODYMIUM	.280E+02	.320E+02	.000E+00	.000E+00	N.000E+00
NICKEL	.830E+03	.210E+03	.100E+01	.190E+00	N.000E+00
NIOBIUM	.480E+02	.140E+02	.000E+00	.000E+00	N.000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.167E+05	.122E+06	.140E+01	.100E+00	N.000E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

ROCK OF AGES
TEST 1 - COAL ONLY
PPM

INPUT DATA

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
POTASSIUM	.117E+05	.439E+05	.500E+01	.900E+00	N.000E+00
PRASEODYMIUM	.240E+02	.140E+02	.000E+00	.000E+00	N.000E+00
RUBIDIUM	.720E+02	.150E+02	.100E+00	.000E+00	N.000E+00
SAMARIUM	.170E+02	.120E+02	.000E+00	.000E+00	N.000E+00
SCANDIUM	.730E+02	.100E+02	<.300E-01	.300E-02	N.000E+00
SELENIUM	<.100E+02	.400E+03	.460E+00	.940E-01	N.000E+00
SILICON	.128E+06	>.100E+04	.000E+00	.560E+01	N.000E+00
SILVER	.350E+02	.120E+02	.000E+00	.800E-01	N.000E+00
SODIUM	.450E+04	.337E+05	.120E+02	.200E+00	N.000E+00
STRONTIUM	.120E+04	.420E+03	.000E+00	.340E-01	N.000E+00
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.159E+05	.331E+05	.160E+02	.380E+01	N.000E+00
TANTALUM	.200E+01	.200E+01	.000E+00	.000E+00	N.000E+00
TELLURIUM	.300E+01	.200E+01	.500E-01	.000E+00	N.000E+00
TERBIUM	.200E+01	.100E+01	.000E+00	.000E+00	N.000E+00
THALLIUM	.400E+02	.310E+02	.000E+00	.700E-01	N.000E+00
THORIUM	.200E+02	.250E+02	.000E+00	.000E+00	N.000E+00
THULIUM	.800E+00	.400E+00	.000E+00	.000E+00	N.000E+00
TIN	.430E+02	.300E+02	.700E-01	.100E+00	N.000E+00
TITANIUM	.680E+04	.510E+04	.470E+01	.170E+00	N.000E+00
TUNGSTEN	.800E+01	.120E+02	.000E+00	.000E+00	N.000E+00
URANIUM	.900E+01	.620E+02	.000E+00	.000E+00	N.000E+00
VANADIUM	.940E+03	.660E+02	.800E-01	.500E-02	N.000E+00
YTTERBIUM	.300E+01	.200E+01	.000E+00	.000E+00	N.000E+00
YTTRIUM	.820E+02	.580E+02	.000E+00	.000E+00	N.000E+00
ZINC	.610E+03	.860E+03	.120E+01	.195E+01	N.000E+00
ZIRCONIUM	.240E+03	.680E+02	.300E-01	.000E+00	N.000E+00

ROCK OF AGES
MASS / FLUE VOLUME
TEST 1 - COAL ONLY
MCG/DSCM

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	.131E+04	.820E+03	.119E+02	.223E+01	N .000E+00
ANTIMONY	.260E+01	.776E+00	.000E+00	.000E+00	.840E-01
ARSENIC	.850E+01	.837E+01	.285E+00	< .445E-01	.000E+00
BARIUM	.330E+02	.143E+02	.237E+01	.601E+01	N .000E+00
BERYLLIUM	.538E+00	.441E+00	.000E+00	.000E+00	N .000E+00
BISMUTH	.104E+00	.304E+00	.000E+00	.000E+00	N .000E+00
BORON	.399E+01	> .152E+02	.142E+00	.111E+00	N .000E+00
BROMINE	.382E+01	.380E+01	.949E+00	.000E+00	N .000E+00
CADMIUM	.243E+00	.117E+01	.000E+00	.111E+01	N .000E+00
CALCIUM	.229E+03	.168E+04	.000E+00	.178E+02	N .000E+00
CERIUM	.260E+01	.928E+00	.000E+00	.000E+00	N .000E+00
CESIUM	.191E+00	.608E-01	.949E+00	.000E+00	N .000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.147E+02	.715E+01	.332E+02	.000E+00	N .000E+00
CHROMIUM	.694E+00	.228E+01	.332E+01	.379E+01	N .000E+00
COBALT	.111E+01	.152E+01	.380E+00	.000E+00	N .000E+00
COPPER	.125E+02	.669E+01	.142E+01	.110E+02	N .000E+00
DYSPROSIUM	.156E+00	.456E-01	.000E+00	.000E+00	N .000E+00
ERBIUM	.694E-01	.152E-01	.000E+00	.000E+00	N .000E+00
EUROPIUM	.520E-01	.456E-01	.000E+00	.000E+00	N .000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.153E+02	> .152E+02	.427E+02	.223E+01	N .000E+00
GADOLINIUM	.104E+00	.608E-01	.000E+00	.000E+00	N .000E+00
GALLIUM	.144E+02	.532E+01	.000E+00	.118E+01	N .000E+00
GERMANIUM	.971E+00	.593E+00	< .285E+00	.000E+00	N .000E+00
HAFNIUM	.347E-01	.152E-01	.000E+00	.000E+00	N .000E+00
HOLMIUM	.104E+00	.304E-01	.000E+00	.000E+00	N .000E+00
IODINE	.503E+00	.913E-01	.949E-01	.000E+00	N .000E+00
IRON	.187E+04	.125E+04	.522E+02	.668E+01	N .000E+00
LANTHANUM	.151E+01	.928E+00	.000E+00	.000E+00	N .000E+00
LEAD	.798E+01	.913E+01	.000E+00	.134E+02	N .000E+00
LITHIUM	.165E+02	> .563E+01	.332E+01	.102E+01	N .000E+00
LUTETIUM	.694E-02	.456E-02	.000E+00	.000E+00	.000E+00
MAGNESIUM	.746E+02	.234E+03	.759E+02	.824E+02	N .000E+00
MANGANESE	.156E+02	.102E+01	.142E+01	.668E+00	N .000E+00
MERCURY	.867E-01	.137E-02	.949E+00	.223E-01	.294E+00
MOLYBDENUM	.146E+01	.989E+00	.142E+01	.000E+00	N .000E+00
NEODYMIUM	.486E+00	.487E+00	.000E+00	.000E+00	N .000E+00
NICKEL	.144E+02	.319E+01	.475E+01	.423E+01	N .000E+00
NIOBIUM	.832E+00	.213E+00	.000E+00	.000E+00	N .000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.290E+03	.186E+04	.664E+01	.223E+01	N .000E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

MASS / FLUE VOLUME

ROCK OF AGES
TEST 1 - COAL ONLY
MCG/DSCM

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
POTASSIUM	.203E+03	.668E+03	.237E+02	.200E+02	N .000E+00
PRASEODYMIUM	.416E+00	.213E+00	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.125E+01	.228E+00	.475E+00	.000E+00	N .000E+00
SAMARIUM	.295E+00	.183E+00	.000E+00	.000E+00	N .000E+00
SCANDIUM	.127E+01	.152E+00	< .142E+00	.668E-01	N .000E+00
SELENIUM	< .173E+00	.608E+01	.218E+01	.209E+01	N .000E+00
SILICON	.222E+04	> .152E+02	.000E+00	.125E+03	N .000E+00
SILVER	.607E+00	.183E+00	.000E+00	.178E+01	N .000E+00
SODIUM	.780E+02	.513E+03	.570E+02	.445E+01	N .000E+00
STRONTIUM	.208E+02	.639E+01	.000E+00	.757E+00	N .000E+00
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.276E+03	.503E+03	.759E+02	.846E+02	N .000E+00
TANTALUM	.347E-01	.304E-01	.000E+00	.000E+00	N .000E+00
TELLURIUM	.520E-01	.304E-01	.237E+00	.000E+00	N .000E+00
TERBIUM	.347E-01	.152E-01	.000E+00	.000E+00	N .000E+00
THALLIUM	.694E+00	.472E+00	.000E+00	.156E+01	N .000E+00
THORIUM	.347E+00	.380E+00	.000E+00	.000E+00	N .000E+00
THULIUM	.139E-01	.608E-02	.000E+00	.000E+00	N .000E+00
TIN	.746E+00	.456E+00	.332E+00	.223E+01	N .000E+00
TITANIUM	.118E+03	.776E+02	.223E+02	.379E+01	N .000E+00
TUNGSTEN	.139E+00	.183E+00	.000E+00	.000E+00	N .000E+00
URANIUM	.156E+00	.943E+00	.000E+00	.000E+00	N .000E+00
VANADIUM	.163E+02	.100E+01	.380E+00	.111E+00	N .000E+00
YTTERBIUM	.520E-01	.304E-01	.000E+00	.000E+00	N .000E+00
YTTRIUM	.142E+01	.882E+00	.000E+00	.000E+00	N .000E+00
ZINC	.106E+02	.131E+02	.570E+01	.434E+02	N .000E+00
ZIRCONIUM	.416E+01	.103E+01	.142E+00	.000E+00	N .000E+00

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                                     ROCK OF AGES
MASS / FLUE VOLUME                   TEST 1 - COAL ONLY
                                       MCG/DSCM
ELEMENT       STACK EXHAUST

ALUMINUM                .215E+04
ANTIMONY                .346E+01
ARSENIC                 .172E+02
BARIUM                  .556E+02
BERYLLIUM               .979E+00

BISMUTH                 .408E+00
BORON                 > .195E+02
BROMINE                 .857E+01
CADMIUM                 .253E+01
CALCIUM                 .193E+04

CERIUM                  .353E+01
CESIUM                  .120E+01
CHLORIDE                .000E+00
CHLORINE                .551E+02
CHROMIUM                .101E+02

COBALT                  .301E+01
COPPER                  .317E+02
DYSPROSIUM              .202E+00
ERBIUM                  .846E-01
EUROPIUM                .977E-01

FLUORIDE                .000E+00
FLUORINE              > .754E+02
GADOLINIUM              .165E+00
GALLIUM                 .209E+02
GERMANIUM         .156E+01<X<.185E+01

HAFNIUM                 .499E-01
HOLMIUM                 .134E+00
IODINE                  .689E+00
IRON                    .318E+04
LANTHANUM               .244E+01

LEAD                    .305E+02
LITHIUM               > .264E+02
LUTETIUM                .115E-01
MAGNESIUM               .467E+03
MANGANESE               .187E+02

MERCURY                 .135E+01
MOLYBDENUM              .387E+01
NEODYMIUM               .972E+00
NICKEL                  .266E+02
NIOBIUM                 .105E+01

NITRATE                 .000E+00
NITRITE                 .000E+00
PHOSPHATE               .000E+00
PHOSPHORUS              .215E+04
PLATINUM                .000E+00
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                                    ROCK OF AGES
MASS / FLUE VOLUME                  TEST 1 - COAL ONLY
                                    MCG/DSCM
ELEMENT         STACK EXHAUST

POTASSIUM               .914E+03
PRASEODYMIUM            .629E+00
RUBIDIUM                .195E+01
SAMARIUM                .477E+00
SCANDIUM        .148E+01<X<.163E+01

SELENIUM        .104E+02<X<.105E+02
SILICON               > .236E+04
SILVER                  .257E+01
SODIUM                  .652E+03
STRONTIUM               .280E+02

SULFATE                 .000E+00
SULFITE                 .000E+00
SULFUR                  .940E+03
TANTALUM                .651E-01
TELLURIUM               .320E+00

TERBIUM                 .499E-01
THALLIUM                .272E+01
THORIUM                 .727E+00
THULIUM                 .200E-01
TIN                     .376E+01

TITANIUM                .222E+03
TUNGSTEN                .321E+00
URANIUM                 .110E+01
VANADIUM                .178E+02
YTTERBIUM               .824E-01

YTTRIUM                 .230E+01
ZINC                    .728E+02
ZIRCONIUM               .534E+01
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MASS / HEAT INPUT

ROCK OF AGES
TEST 1 - COAL ONLY
NG/J

ELEMENT	FUEL: COAL	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
ALUMINUM	.381E+03	.524E+03	.706E+01	.138E+01
ANTIMONY	< .320E-01	.163E-01	.754E-03	.223E-02
ARSENIC	.352E+00	.163E-01	.654E-02	.111E-01
BARIUM	.320E+01	.142E+01	.163E-01	.358E-01
BERYLLIUM	.288E+00	.894E-01	.880E-03	.630E-03
BISMUTH	.000E+00	.000E+00	.503E-04	.263E-03
BORON	.959E+00	.126E+00	.138E-01	> .125E-01
BROMINE	.672E+00	.163E-01	.616E-02	.552E-02
CADMIUM	.320E-01	.163E-02	.503E-04	.163E-02
CALCIUM	.617E+02	.484E+02	.842E+00	.124E+01
CERIUM	.576E+00	.894E-01	.503E-03	.227E-02
CESIUM	.160E-01	.813E-02	.503E-04	.773E-03
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.640E+02	.398E+00	.314E-01	.355E-01
CHROMIUM	.384E+01	.203E+00	.641E-02	.649E-02
COBALT	.256E+00	.894E-01	.754E-03	.194E-02
COPPER	.448E+00	.732E-01	.427E-02	.204E-01
DYSPROSIUM	.000E+00	.122E-01	.126E-03	.130E-03
ERBIUM	.000E+00	.813E-02	.628E-04	.545E-04
EUROPIUM	.959E-02	.813E-02	.503E-04	.629E-04
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.265E+02	< .407E+00	.327E-01	> .486E-01
GADOLINIUM	.224E-01	.122E-01	.113E-03	.106E-03
GALLIUM	.512E+00	.407E-01	.239E-02	.135E-01
GERMANIUM	.320E-01	.407E-02	.503E-03	.101E-02<X<.119E-02
HAFNIUM	.000E+00	.122E-01	.377E-04	.321E-04
HOLMIUM	.000E+00	.813E-02	.880E-04	.866E-04
IODINE	.320E-01	.813E-02	.377E-03	.444E-03
IRON	.109E+03	.193E+03	.120E+02	.205E+01
LANTHANUM	.800E+00	.122E+00	.754E-03	.157E-02
LEAD	.959E-01	.366E-01	.176E-02	.196E-01
LITHIUM	.237E+01	.488E+00	.993E-02	> .170E-01
LUTETIUM	.000E+00	.122E-02	< .126E-04	.741E-05
MAGNESIUM	.154E+02	.187E+02	.189E+00	.301E+00
MANGANESE	.256E+00	.528E-01	.138E-02	.121E-01
MERCURY	.288E-02	< .407E-04	.980E-04	.872E-03
MOLYBDENUM	.864E+00	.244E-01	.101E-02	.249E-02
NEODYMIUM	.224E+00	.569E-01	.377E-03	.626E-03
NICKEL	.640E-01	.650E+00	.993E-02	.171E-01
NIOBIUM	.384E+00	.366E-01	.503E-03	.673E-03
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.320E+01	.301E+01	.339E+00	.139E+01
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00

MASS / HEAT INPUT

ROCK OF AGES
TEST 1 - COAL ONLY
NG/J

ELEMENT	FUEL: COAL	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
POTASSIUM	.371E+02	.504E+02	.641E+00	.589E+00
PRASEODYMIUM	.959E-01	.285E-01	.126E-03	.405E-03
RUBIDIUM	.160E+00	.325E-01	.251E-03	.126E-02
SAMARIUM	.320E-01	.285E-01	.377E-03	.307E-03
SCANDIUM	.112E+01	.122E+00	.327E-02	.956E-03<X<.105E-02
SELENIUM	.416E+01	.528E-01	.214E-01	.667E-02<X<.679E-02
SILICON	.598E+03	.860E+03	.103E+02	> .152E+01
SILVER	.000E+00	.203E-02	.628E-04	.166E-02
SODIUM	.166E+02	.228E+02	.327E+00	.420E+00
STRONTIUM	.352E+01	.854E+00	.113E-01	.180E-01
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.320E+03	.130E+01	.509E+01	.605E+00
TANTALUM	.000E+00	.366E-02	.503E-04	.419E-04
TELLURIUM	.000E+00	< .813E-03	.503E-04	.206E-03
TERBIUM	.640E-02	.325E-02	.251E-04	.321E-04
THALLIUM	.000E+00	.407E-02	.251E-03	.175E-02
THORIUM	.160E+00	.569E-01	.251E-03	.468E-03
THULIUM	.000E+00	.813E-03	.251E-04	.129E-04
TIN	.160E-01	.325E-02	.126E-03	.242E-02
TITANIUM	.173E+02	.276E+02	.440E+00	.143E+00
TUNGSTEN	.000E+00	.407E-02	.628E-04	.207E-03
URANIUM	.640E-01	.366E-01	.251E-03	.708E-03
VANADIUM	.128E+01	.179E+00	.107E-01	.115E-01
YTTERBIUM	.000E+00	.407E-02	.628E-04	.531E-04
YTTRIUM	.320E+00	.447E-01	.628E-03	.148E-02
ZINC	.170E+01	.447E-01	.465E-02	.469E-01
ZIRCONIUM	.991E+00	.138E+00	.101E-02	.344E-02

MASS / HEAT INPUT

ROCK OF AGES
TEST 1 - COAL ONLY
NG/J

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	.847E+00	.528E+00	.764E-02	.143E-02	N .000E+00
ANTIMONY	.168E-02	.500E-03	.000E+00	.000E+00	.541E-04
ARSENIC	.547E-02	.539E-02	.183E-03	< .287E-04	.000E+00
BARIUM	.212E-01	.921E-02	.153E-02	.387E-02	N .000E+00
BERYLLIUM	.346E-03	.284E-03	.000E+00	.000E+00	N .000E+00
BISMUTH	.670E-04	.196E-03	.000E+00	.000E+00	N .000E+00
BORON	.257E-02	> .980E-02	.917E-04	.717E-04	N .000E+00
BROMINE	.246E-02	.245E-02	.611E-03	.000E+00	N .000E+00
CADMIUM	.156E-03	.754E-03	.000E+00	.717E-03	N .000E+00
CALCIUM	.147E+00	.108E+01	.000E+00	.115E-01	N .000E+00
CERIUM	.168E-02	.598E-03	.000E+00	.000E+00	N .000E+00
CESIUM	.123E-03	.392E-04	.611E-03	.000E+00	N .000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.949E-02	.460E-02	.214E-01	.000E+00	N .000E+00
CHROMIUM	.447E-03	.147E-02	.214E-02	.244E-02	N .000E+00
COBALT	.715E-03	.980E-03	.245E-03	.000E+00	N .000E+00
COPPER	.806E-02	.431E-02	.917E-03	.712E-02	N .000E+00
DYSPROSIUM	.101E-03	.294E-04	.000E+00	.000E+00	N .000E+00
ERBIUM	.447E-04	.980E-05	.000E+00	.000E+00	N .000E+00
EUROPIUM	.335E-04	.294E-04	.000E+00	.000E+00	N .000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.983E-02	> .980E-02	.275E-01	.143E-02	N .000E+00
GADOLINIUM	.670E-04	.392E-04	.000E+00	.000E+00	N .000E+00
GALLIUM	.927E-02	.343E-02	.000E+00	.760E-03	N .000E+00
GERMANIUM	.626E-03	.382E-03	< .183E-03	.000E+00	N .000E+00
HAFNIUM	.223E-04	.980E-05	.000E+00	.000E+00	N .000E+00
HOLMIUM	.670E-04	.196E-04	.000E+00	.000E+00	N .000E+00
IODINE	.324E-03	.588E-04	.611E-04	.000E+00	N .000E+00
IRON	.121E+01	.804E+00	.336E-01	.430E-02	N .000E+00
LANTHANUM	.972E-03	.598E-03	.000E+00	.000E+00	N .000E+00
LEAD	.514E-02	.588E-02	.000E+00	.861E-02	N .000E+00
LITHIUM	.106E-01	> .362E-02	.214E-02	.660E-03	N .000E+00
LUTETIUM	.447E-05	.294E-05	.000E+00	.000E+00	.000E+00
MAGNESIUM	.480E-01	.151E+00	.489E-01	.531E-01	N .000E+00
MANGANESE	.101E-01	.656E-03	.917E-03	.430E-03	N .000E+00
MERCURY	.559E-04	.882E-06	.611E-03	.143E-04	.189E-03
MOLYBDENUM	.938E-03	.637E-03	.917E-03	.000E+00	N .000E+00
NEODYMIUM	.313E-03	.313E-03	.000E+00	.000E+00	N .000E+00
NICKEL	.927E-02	.206E-02	.306E-02	.273E-02	N .000E+00
NIOBIUM	.536E-03	.137E-03	.000E+00	.000E+00	N .000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.187E+00	.120E+01	.428E-02	.143E-02	N .000E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

MASS / HEAT INPUT

ROCK OF AGES
TEST 1 - COAL ONLY
NG/J

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
POTASSIUM	.131E+00	.430E+00	.153E-01	.129E-01	N .000E+00
PRASEODYMIUM	.268E-03	.137E-03	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.804E-03	.147E-03	.306E-03	.000E+00	N .000E+00
SAMARIUM	.190E-03	.118E-03	.000E+00	.000E+00	N .000E+00
SCANDIUM	.815E-03	.980E-04	< .917E-04	.430E-04	N .000E+00
SELENIUM	< .112E-03	.392E-02	.141E-02	.135E-02	N .000E+00
SILICON	.143E+01	> .980E-02	.000E+00	.803E-01	N .000E+00
SILVER	.391E-03	.118E-03	.000E+00	.115E-02	N .000E+00
SODIUM	.503E-01	.330E+00	.367E-01	.287E-02	N .000E+00
STRONTIUM	.134E-01	.411E-02	.000E+00	.488E-03	N .000E+00
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.178E+00	.324E+00	.489E-01	.545E-01	N .000E+00
TANTALUM	.223E-04	.196E-04	.000E+00	.000E+00	N .000E+00
TELLURIUM	.335E-04	.196E-04	.153E-03	.000E+00	N .000E+00
TERBIUM	.223E-04	.980E-05	.000E+00	.000E+00	N .000E+00
THALLIUM	.447E-03	.304E-03	.000E+00	.100E-02	N .000E+00
THORIUM	.223E-03	.245E-03	.000E+00	.000E+00	N .000E+00
THULIUM	.894E-05	.392E-05	.000E+00	.000E+00	N .000E+00
TIN	.480E-03	.294E-03	.214E-03	.143E-02	N .000E+00
TITANIUM	.760E-01	.500E-01	.144E-01	.244E-02	N .000E+00
TUNGSTEN	.894E-04	.118E-03	.000E+00	.000E+00	N .000E+00
URANIUM	.101E-03	.607E-03	.000E+00	.000E+00	N .000E+00
VANADIUM	.105E-01	.647E-03	.245E-03	.717E-04	N .000E+00
YTTERBIUM	.335E-04	.196E-04	.000E+00	.000E+00	N .000E+00
YTTRIUM	.916E-03	.568E-03	.000E+00	.000E+00	N .000E+00
ZINC	.681E-02	.843E-02	.367E-02	.280E-01	N .000E+00
ZIRCONIUM	.268E-02	.666E-03	.917E-04	.000E+00	N .000E+00

ROCK OF AGES
TEST 1 - COAL ONLY
MCG/SEC

MASS / TIME

ELEMENT	FUEL: COAL	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
ALUMINUM	.357E+06	.505E+06	.681E+04	.133E+04
ANTIMONY	< .300E+02	.157E+02	.727E+00	.215E+01
ARSENIC	.330E+03	.157E+02	.630E+01	.107E+02
BARIUM	.300E+04	.137E+04	.158E+02	.346E+02
BERYLLIUM	.270E+03	.862E+02	.848E+00	.608E+00
BISMUTH	.000E+00	.000E+00	.485E-01	.254E+00
BORON	.900E+03	.122E+03	.133E+02	> .121E+02
BROMINE	.630E+03	.157E+02	.594E+01	.532E+01
CADMIUM	.300E+02	.157E+01	.485E-01	.157E+01
CALCIUM	.579E+05	.466E+05	.812E+03	.120E+04
CERIUM	.540E+03	.862E+02	.485E+00	.219E+01
CESIUM	.150E+02	.784E+01	.485E-01	.746E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.600E+05	.384E+03	.303E+02	.342E+02
CHROMIUM	.360E+04	.196E+03	.618E+01	.626E+01
COBALT	.240E+03	.862E+02	.727E+00	.187E+01
COPPER	.420E+03	.706E+02	.412E+01	.197E+02
DYSPROSIUM	.000E+00	.118E+02	.121E+00	.125E+00
ERBIUM	.000E+00	.784E+01	.606E-01	.525E-01
EUROPIUM	.900E+01	.784E+01	.485E-01	.607E-01
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.249E+05	< .392E+03	.315E+02	> .468E+02
GADOLINIUM	.210E+02	.118E+02	.109E+00	.102E+00
GALLIUM	.480E+03	.392E+02	.230E+01	.130E+02
GERMANIUM	.300E+02	.392E+01	.485E+00	.972E+00<X<.115E+01
HAFNIUM	.000E+00	.118E+02	.364E-01	.310E-01
HOLMIUM	.000E+00	.784E+01	.848E-01	.835E-01
IODINE	.300E+02	.784E+01	.364E+00	.428E+00
IRON	.102E+06	.186E+06	.115E+05	.197E+04
LANTHANUM	.750E+03	.118E+03	.727E+00	.151E+01
LEAD	.900E+02	.353E+02	.170E+01	.189E+02
LITHIUM	.222E+04	.470E+03	.957E+01	> .164E+02
LUTETIUM	.000E+00	.118E+01	< .121E-01	.714E-02
MAGNESIUM	.144E+05	.180E+05	.182E+03	.290E+03
MANGANESE	.240E+03	.510E+02	.133E+01	.116E+02
MERCURY	.270E+01	< .392E-01	.945E-01	.841E+00
MOLYBDENUM	.810E+03	.235E+02	.970E+00	.240E+01
NEODYMIUM	.210E+03	.549E+02	.364E+00	.604E+00
NICKEL	.600E+02	.627E+03	.957E+01	.165E+02
NIOBIUM	.360E+03	.353E+02	.485E+00	.649E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.300E+04	.290E+04	.327E+03	.134E+04
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00

ROCK OF AGES
MASS / TIME TEST 1 - COAL ONLY
MCG/SEC

ELEMENT	FUEL: COAL	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
POTASSIUM	.348E+05	.486E+05	.618E+03	.568E+03
PRASEODYMIUM	.900E+02	.274E+02	.121E+00	.391E+00
RUBIDIUM	.150E+03	.314E+02	.242E+00	.121E+01
SAMARIUM	.300E+02	.274E+02	.364E+00	.296E+00
SCANDIUM	.105E+04	.118E+03	.315E+01	.922E+00<X<.101E+01
SELENIUM	.390E+04	.510E+02	.206E+02	.644E+01<X<.654E+01
SILICON	.561E+06	.829E+06	.994E+04	> .147E+04
SILVER	.000E+00	.196E+01	.606E-01	.160E+01
SODIUM	.156E+05	.220E+05	.315E+03	.405E+03
STRONTIUM	.330E+04	.823E+03	.109E+02	.174E+02
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.300E+06	.125E+04	.491E+04	.584E+03
TANTALUM	.000E+00	.353E+01	.485E-01	.404E-01
TELLURIUM	.000E+00	< .784E+00	.485E-01	.199E+00
TERBIUM	.600E+01	.314E+01	.242E-01	.310E-01
THALLIUM	.000E+00	.392E+01	.242E+00	.169E+01
THORIUM	.150E+03	.549E+02	.242E+00	.452E+00
THULIUM	.000E+00	.784E+00	.242E-01	.124E-01
TIN	.150E+02	.314E+01	.121E+00	.234E+01
TITANIUM	.162E+05	.267E+05	.424E+03	.138E+03
TUNGSTEN	.000E+00	.392E+01	.606E-01	.200E+00
URANIUM	.600E+02	.353E+02	.242E+00	.683E+00
VANADIUM	.120E+04	.172E+03	.103E+02	.111E+02
YTTERBIUM	.000E+00	.392E+01	.606E-01	.512E-01
YTTRIUM	.300E+03	.431E+02	.606E+00	.143E+01
ZINC	.159E+04	.431E+02	.448E+01	.452E+02
ZIRCONIUM	.930E+03	.133E+03	.970E+00	.332E+01

ROCK OF AGES
TEST 1 - COAL ONLY
MCG/SEC

MASS / TIME

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	.816E+03	.509E+03	.737E+01	.138E+01	N .000E+00
ANTIMONY	.162E+01	.482E+00	.000E+00	.000E+00	.522E-01
ARSENIC	.528E+01	.520E+01	.177E+00	< .277E-01	.000E+00
BARIUM	.205E+02	.888E+01	.147E+01	.373E+01	N .000E+00
BERYLLIUM	.334E+00	.274E+00	.000E+00	.000E+00	N .000E+00
BISMUTH	.646E-01	.189E+00	.000E+00	.000E+00	N .000E+00
BORON	.248E+01	> .945E+01	.884E-01	.692E-01	N .000E+00
BROMINE	.237E+01	.236E+01	.590E+00	.000E+00	N .000E+00
CADMIUM	.151E+00	.727E+00	.000E+00	.692E+00	N .000E+00
CALCIUM	.142E+03	.104E+04	.000E+00	.111E+02	N .000E+00
CERIUM	.162E+01	.576E+00	.000E+00	.000E+00	N .000E+00
CESIUM	.118E+00	.378E-01	.590E+00	.000E+00	N .000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.916E+01	.444E+01	.206E+02	.000E+00	N .000E+00
CHROMIUM	.431E+00	.142E+01	.206E+01	.235E+01	N .000E+00
COBALT	.689E+00	.945E+00	.236E+00	.000E+00	N .000E+00
COPPER	.778E+01	.416E+01	.884E+00	.686E+01	N .000E+00
DYSPROSIUM	.969E-01	.283E-01	.000E+00	.000E+00	N .000E+00
ERBIUM	.431E-01	.945E-02	.000E+00	.000E+00	N .000E+00
EUROPIUM	.323E-01	.283E-01	.000E+00	.000E+00	N .000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.948E+01	> .945E+01	.265E+02	.138E+01	N .000E+00
GADOLINIUM	.646E-01	.378E-01	.000E+00	.000E+00	N .000E+00
GALLIUM	.894E+01	.331E+01	.000E+00	.733E+00	N .000E+00
GERMANIUM	.603E+00	.368E+00	< .177E+00	.000E+00	N .000E+00
HAFNIUM	.215E-01	.945E-02	.000E+00	.000E+00	N .000E+00
HOLMIUM	.646E-01	.189E-01	.000E+00	.000E+00	N .000E+00
IODINE	.312E+00	.567E-01	.590E-01	.000E+00	N .000E+00
IRON	.116E+04	.776E+03	.324E+02	.415E+01	N .000E+00
LANTHANUM	.937E+00	.576E+00	.000E+00	.000E+00	N .000E+00
LEAD	.495E+01	.567E+01	.000E+00	.830E+01	N .000E+00
LITHIUM	.102E+02	> .350E+01	.206E+01	.636E+00	N .000E+00
LUTETIUM	.431E-02	.283E-02	.000E+00	.000E+00	.000E+00
MAGNESIUM	.463E+02	.145E+03	.472E+02	.512E+02	N .000E+00
MANGANESE	.969E+01	.633E+00	.884E+00	.415E+00	N .000E+00
MERCURY	.539E-01	.850E-03	.590E+00	.138E-01	.183E+00
MOLYBDENUM	.905E+00	.614E+00	.884E+00	.000E+00	N .000E+00
NEODYMIUM	.302E+00	.302E+00	.000E+00	.000E+00	N .000E+00
NICKEL	.894E+01	.198E+01	.295E+01	.263E+01	N .000E+00
NIOBIUM	.517E+00	.132E+00	.000E+00	.000E+00	N .000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.180E+03	.115E+04	.413E+01	.138E+01	N .000E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

ROCK OF AGES
TEST 1 - COAL ONLY
MCG/SEC

MASS / TIME ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
POTASSIUM	.126E+03	.415E+03	.147E+02	.124E+02	N .000E+00
PRASEODYMIUM	.259E+00	.132E+00	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.776E+00	.142E+00	.295E+00	.000E+00	N .000E+00
SAMARIUM	.183E+00	.113E+00	.000E+00	.000E+00	N .000E+00
SCANDIUM	.786E+00	.945E-01	< .884E-01	.415E-01	N .000E+00
SELENIUM	< .108E+00	.378E+01	.136E+01	.130E+01	N .000E+00
SILICON	.138E+04	> .945E+01	.000E+00	.775E+02	N .000E+00
SILVER	.377E+00	.113E+00	.000E+00	.111E+01	N .000E+00
SODIUM	.485E+02	.318E+03	.354E+02	.277E+01	N .000E+00
STRONTIUM	.129E+02	.397E+01	.000E+00	.470E+00	N .000E+00
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.171E+03	.313E+03	.472E+02	.526E+02	N .000E+00
TANTALUM	.215E-01	.189E-01	.000E+00	.000E+00	N .000E+00
TELLURIUM	.323E-01	.189E-01	.147E+00	.000E+00	N .000E+00
TERBIUM	.215E-01	.945E-02	.000E+00	.000E+00	N .000E+00
THALLIUM	.431E+00	.293E+00	.000E+00	.968E+00	N .000E+00
THORIUM	.215E+00	.236E+00	.000E+00	.000E+00	N .000E+00
THULIUM	.862E-02	.378E-02	.000E+00	.000E+00	N .000E+00
TIN	.463E+00	.283E+00	.206E+00	.138E+01	N .000E+00
TITANIUM	.732E+02	.482E+02	.139E+02	.235E+01	N .000E+00
TUNGSTEN	.862E-01	.113E+00	.000E+00	.000E+00	N .000E+00
URANIUM	.969E-01	.586E+00	.000E+00	.000E+00	N .000E+00
VANADIUM	.101E+02	.624E+00	.236E+00	.692E-01	N .000E+00
YTTERBIUM	.323E-01	.189E-01	.000E+00	.000E+00	N .000E+00
YTTRIUM	.883E+00	.548E+00	.000E+00	.000E+00	N .000E+00
ZINC	.657E+01	.812E+01	.354E+01	.270E+02	N .000E+00
ZIRCONIUM	.259E+01	.642E+00	.884E-01	.000E+00	N .000E+00

ROCK OF AGES
TEST 1 - COAL ONLY

BOILER MASS BALANCE
INPUT = FUEL; OUTPUT = BOTTOM ASH + CYCLONE ASH + SASS TRAIN

ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE (OUT/IN)
ALUMINUM	.357E+06	.513E+06	.144E+01
ANTIMONY	X<.300E+02	.186E+02	.619E+00 <X
ARSENIC	.330E+03	.327E+02	.990E-01
BARIUM	.300E+04	.142E+04	.474E+00
BERYLLIUM	.270E+03	.877E+02	.325E+00
BISMUTH		.302E+00	*
BORON	.900E+03	.147E+03 <X	.163E+00 <X
BROMINE	.630E+03	.269E+02	.428E-01
CADMIUM	.300E+02	.319E+01	.106E+00
CALCIUM	.579E+05	.487E+05	.840E+00
CERIUM	.540E+03	.889E+02	.165E+00
CESIUM	.150E+02	.863E+01	.576E+00
CHLORIDE			*
CHLORINE	.600E+05	.449E+03	.748E-02
CHROMIUM	.360E+04	.208E+03	.579E-01
COBALT	.240E+03	.888E+02	.370E+00
COPPER	.420E+03	.944E+02	.225E+00
DYSPROSIUM		.120E+02	*
ERBIUM		.795E+01	*
EUROPIUM	.900E+01	.795E+01	.883E+00
FLUORIDE			*
FLUORINE	.249E+05	.784E+02 <X	.315E-02 <X
GADOLINIUM	.210E+02	.120E+02	.570E+00
GALLIUM	.480E+03	.545E+02	.114E+00
GERMANIUM	.300E+02	.538E+01<X<.555E+01	.179E+00<X<.185E+00
HAFNIUM		.118E+02	*
HOLMIUM		.801E+01	*
IODINE	.300E+02	.863E+01	.288E+00
IRON	.102E+06	.200E+06	.196E+01
LANTHANUM	.750E+03	.120E+03	.160E+00
LEAD	.900E+02	.559E+02	.621E+00
LITHIUM	.222E+04	.496E+03 <X	.224E+00 <X
LUTETIUM		.118E+01<X<.120E+01	*
MAGNESIUM	.144E+05	.185E+05	.128E+01
MANGANESE	.240E+03	.639E+02	.266E+00
MERCURY	.270E+01	.935E+00<X<.974E+00	.346E+00<X<.361E+00
MOLYBDENUM	.810E+03	.269E+02	.332E-01
NEODYMIUM	.210E+03	.558E+02	.266E+00
NICKEL	.600E+02	.653E+03	.109E+02
NIOBIUM	.360E+03	.364E+02	.101E+00
NITRATE			*
NITRITE			*
PHOSPHATE			*
PHOSPHORUS	.300E+04	.457E+04	.152E+01
PLATINUM			*

ROCK OF AGES
TEST 1 - COAL ONLY

BOILER MASS BALANCE
INPUT = FUEL; OUTPUT = BOTTOM ASH + CYCLONE ASH + SASS TRAIN

ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE (OUT/IN)
POTASSIUM	.348E+05	.498E+05	.143E+01
PRASEODYMIUM	.900E+02	.280E+02	.311E+00
RUBIDIUM	.150E+03	.328E+02	.219E+00
SAMARIUM	.300E+02	.281E+02	.937E+00
SCANDIUM	.105E+04	.122E+03	.116E+00
SELENIUM	.390E+04	.781E+02	.200E-01
SILICON	.561E+06	.841E+06 <X	.150E+01 <X
SILVER		.362E+01	*
SODIUM	.156E+05	.227E+05	.145E+01
STRONTIUM	.330E+04	.851E+03	.258E+00
SULFATE			*
SULFITE			*
SULFUR	.300E+06	.675E+04	.225E-01
TANTALUM		.362E+01	*
TELLURIUM		.247E+00<X<.103E+01	*
TERBIUM	.600E+01	.319E+01	.532E+00
THALLIUM		.585E+01	*
THORIUM	.150E+03	.556E+02	.370E+00
THULIUM		.821E+00	*
TIN	.150E+02	.559E+01	.373E+00
TITANIUM	.162E+05	.272E+05	.168E+01
TUNGSTEN		.418E+01	*
URANIUM	.600E+02	.362E+02	.603E+00
VANADIUM	.120E+04	.194E+03	.162E+00
YTTERBIUM		.403E+01	*
YTTRIUM	.300E+03	.452E+02	.151E+00
ZINC	.159E+04	.928E+02	.584E-01
ZIRCONIUM	.930E+03	.138E+03	.148E+00

INPUT DATA

ROCK OF AGES
TEST2 - COAL/PET
PPM

ELEMENT	FUEL - COAL/PET	FUEL - PET	BOTTOM ASH	BOTTOM ASH LEACHATE
ALUMINUM	.156E+05	>.100E+04	.164E+06	.140E+02
ANTIMONY	.240E+02	.220E+02	.150E+02	.200E+00
ARSENIC	.300E+01	<.100E+00	.700E+01	.100E-01
BARIUM	.410E+02	.170E+02	.985E+03	.300E+00
BERYLLIUM	.800E+00	.000E+00	.240E+02	.000E+00
BISMUTH	.200E+01	.500E+00	.000E+00	.000E+00
BORON	.140E+02	.700E+00	.130E+03	.400E+00
BROMINE	.100E+02	.000E+00	.500E+01	.800E-01
CADMIUM	.200E+01	.200E+01	.400E+01	.400E-02
CALCIUM	.930E+03	.530E+02	.259E+05	.530E+02
CERIUM	.400E+01	<.100E+00	.420E+02	.000E+00
CESIUM	.900E+00	.000E+00	.500E+01	.000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.130E+01
CHLORINE	.230E+04	.700E+03	.360E+02	.300E+01
CHROMIUM	.430E+02	.110E+02	.220E+03	.600E-01
COBALT	.900E+01	.130E+02	.110E+03	<.300E-02
COPPER	.270E+02	.380E+02	.480E+02	.300E-01
DYSPROSIUM	.000E+00	.000E+00	.800E+01	.000E+00
ERBIUM	.000E+00	.000E+00	.400E+01	.000E+00
EUROPIUM	.000E+00	.000E+00	.400E+01	.000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.100E+00
FLUORINE	.710E+02	.200E+03	.250E+03	.700E+01
GADOLINIUM	.000E+00	.000E+00	.800E+01	.000E+00
GALLIUM	.500E+01	.300E+01	.630E+02	.900E-01
GERMANIUM	<.100E+00	<.100E+00	.400E+01	.100E-01
HAFNIUM	.000E+00	.000E+00	.500E+01	.000E+00
HOLMIUM	.000E+00	.000E+00	.500E+01	.000E+00
IODINE	.900E+00	<.100E+00	.700E+00	.100E-01
IRON	.380E+04	.220E+02	.386E+05	.600E+00
LANTHANUM	.600E+01	.000E+00	.660E+02	.000E+00
LEAD	.280E+02	.320E+02	.520E+02	.900E-02
LITHIUM	.500E+01	.220E+02	.540E+02	.700E-01
LUTETIUM	.000E+00	.000E+00	.900E+00	.000E+00
MAGNESIUM	.370E+03	.400E+02	.470E+04	.900E+00
MANGANESE	.170E+02	.400E+01	.720E+02	.500E-02
MERCURY	.200E+00	.350E+00	<.100E-01	<.100E-02
MOLYBDENUM	.170E+02	.800E+01	.160E+02	.500E+00
NEODYMIUM	.400E+01	.000E+00	.320E+02	.000E+00
NICKEL	.340E+03	.290E+03	.150E+03	.200E-01
NIOBIUM	.200E+01	.000E+00	.150E+02	.300E-02
NITRATE	.000E+00	.000E+00	.000E+00	<.100E+01
NITRITE	.000E+00	.000E+00	.000E+00	<.100E+01
PHOSPHATE	.000E+00	.000E+00	.000E+00	<.100E+01
PHOSPHORUS	.170E+03	.530E+02	.100E+04	.300E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00

INPUT DATA

ROCK OF AGES
TEST2 - COAL/PET
PPM

ELEMENT	FUEL - COAL/PET	FUEL - PET	BOTTOM ASH	BOTTOM ASH LEACHATE
POTASSIUM	.910E+03	.110E+02	.114E+05	.510E+01
PRASEODYMIUM	.200E+01	.000E+00	.100E+02	.000E+00
RUBIDIUM	.200E+01	<.100E+00	.250E+02	.200E-01
SAMARIUM	.100E+01	.000E+00	.150E+02	.000E+00
SCANDIUM	.900E+01	<.100E+00	.410E+02	<.200E-02
SELENIUM	.400E+01	.000E+00	.170E+02	.100E+00
SILICON	.137E+05	.700E+03	.213E+06	.500E+01
SILVER	.000E+00	.000E+00	.600E+00	<.400E-02
SODIUM	.370E+03	.180E+03	.520E+04	.710E+01
STRONTIUM	.240E+02	<.100E+00	.510E+03	.300E+01
SULFATE	.000E+00	.000E+00	.000E+00	.220E+03
SULFITE	.000E+00	.000E+00	.000E+00	.200E+02
SULFUR	.660E+04	.830E+03	.540E+04	.900E+02
TANTALUM	.300E+01	.000E+00	.500E+01	.000E+00
TELLURIUM	.000E+00	.000E+00	.300E+00	.000E+00
TERBIUM	.000E+00	.000E+00	.300E+01	.000E+00
THALLIUM	.000E+00	.300E+00	.400E+01	.000E+00
THORIUM	.400E+01	.000E+00	.310E+02	.000E+00
THULIUM	.000E+00	.000E+00	.100E+01	.000E+00
TIN	.900E+00	.000E+00	.200E+01	.000E+00
TITANIUM	.480E+03	.840E+02	.740E+04	.200E+00
TUNGSTEN	.000E+00	.800E+00	.400E+01	.200E-01
URANIUM	.200E+01	.000E+00	.220E+02	.000E+00
VANADIUM	.110E+02	.400E+00	.240E+02	.500E-01
YTTERBIUM	.000E+00	.000E+00	.700E+01	.000E+00
YTTRIUM	.400E+01	<.100E+00	.620E+02	.900E-02
ZINC	.100E+02	.600E+01	.230E+02	.600E-01
ZIRCONIUM	.800E+01	.200E+00	.920E+02	.100E-01

ROCK OF AGES
INPUT DATA TEST2 - COAL/PET
PPM

ELEMENT	CYCLONE ASH	CYCLONE ASH LEACHATE
ALUMINUM	.666E+05	.110E+04
ANTIMONY	.260E+02	.500E-01
ARSENIC	.700E+02	.200E+00
BARIUM	.360E+03	.500E-01
BERYLLIUM	.100E+02	.700E-01
BISMUTH	.100E+01	.000E+00
BORON	.840E+03	.200E+00
BROMINE	.770E+02	.800E-01
CADMIUM	.800E+01	.100E+00
CALCIUM	.227E+05	.190E+01
CERIUM	.220E+02	.200E+00
CESIUM	.200E+01	.200E-01
CHLORIDE	.000E+00	.180E+03
CHLORINE	.250E+03	.700E+00
CHROMIUM	.680E+02	.100E+01
COBALT	.100E+02	.100E+01
COPPER	.450E+02	.600E+01
DYSPROSIUM	.500E+01	.200E-01
ERBIUM	.200E+01	.800E-02
EUROPIUM	.800E+00	.100E-01
FLUORIDE	.000E+00	.180E+01
FLUORINE	.380E+03	.380E+02
GADOLINIUM	.200E+01	.300E-01
GALLIUM	.220E+02	.500E+01
GERMANIUM	.800E+01	.700E-01
HAFNIUM	<.700E+00	.400E-02
HOLMIUM	.300E+01	.100E-01
IODINE	.800E+01	.100E-02
IRON	.113E+06	.540E+03
LANTHANUM	.350E+02	.300E+00
LEAD	.700E+02	.100E+00
LITHIUM	.380E+03	.440E+01
LUTETIUM	.200E+00	.200E-02
MAGNESIUM	.430E+04	.960E+02
MANGANESE	.270E+02	.180E+02
MERCURY	.115E+01	<.100E-02
MOLYBDENUM	.200E+02	.200E-01
NEODYMIUM	.150E+02	.200E+00
NICKEL	.390E+02	.800E+00
NIOBIUM	.900E+01	.500E-02
NITRATE	.000E+00	<.100E+02
NITRITE	.000E+00	<.100E+02
PHOSPHATE	.000E+00	<.100E+02
PHOSPHORUS	.330E+04	<.100E-01
PLATINUM	.000E+00	.000E+00

INPUT DATA

ROCK OF AGES
TEST2 - COAL/PET
PPM

ELEMENT	CYCLONE ASH	CYCLONE ASH LEACHATE
POTASSIUM	.640E+04	.560E+02
PRASEODYMIUM	.700E+01	.800E-01
RUBIDIUM	.500E+01	.100E+00
SAMARIUM	.400E+01	.600E-01
SCANDIUM	.800E+01	.100E+00
SELENIUM	.130E+03	.200E+00
SILICON	.984E+05	.210E+03
SILVER	.100E+01	.000E+00
SODIUM	.270E+04	.170E+03
STRONTIUM	.170E+03	.400E+01
SULFATE	.000E+00	.120E+05
SULFITE	.000E+00	.500E+04
SULFUR	.281E+05	.390E+04
TANTALUM	.100E+01	.500E-02
TELLURIUM	.400E+00	.100E-02
TERBIUM	.600E+00	.700E-02
THALLIUM	.140E+02	.900E-01
THORIUM	.110E+02	.100E-01
THULIUM	.400E+00	.200E-02
TIN	.500E+01	.300E-02
TITANIUM	.450E+04	.500E+00
TUNGSTEN	.200E+01	<.300E-02
URANIUM	.120E+02	.500E-01
VANADIUM	.450E+02	.300E+00
YTTERBIUM	.100E+01	.300E-01
YTTRIUM	.110E+02	.500E+00
ZINC	.880E+02	.120E+02
ZIRCONIUM	.190E+02	.100E-01

INPUT DATA

ROCK OF AGES
TEST2 - COAL/PET
PPM

ELEMENT	10U + 3U CYCLONES	FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGER
ALUMINUM	.903E+05	.130E+05	.150E+01	.500E+00	N.000E+00
ANTIMONY	.680E+03	<.100E+03	.000E+00	.000E+00	.100E-02
ARSENIC	.810E+03	.130E+04	.200E-01	.700E-02	.000E+00
BARIUM	.830E+03	.530E+02	.100E+00	.000E+00	N.000E+00
BERYLLIUM	.430E+02	.250E+02	.000E+00	.000E+00	N.000E+00
BISMUTH	.200E+02	.860E+02	.000E+00	.000E+00	N.000E+00
BORON	<.800E+02	>.100E+04	.600E-01	.600E-02	N.000E+00
BROMINE	.220E+03	.240E+03	.300E+00	.700E-01	N.000E+00
CADMIUM	.670E+02	.700E+03	.000E+00	.000E+00	N.000E+00
CALCIUM	.137E+05	.250E+04	.000E+00	.200E+01	N.000E+00
CERIUM	.750E+02	.300E+01	.000E+00	.000E+00	N.000E+00
CESIUM	.400E+01	.160E+02	.200E+00	.700E-02	N.000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.420E+04	.300E+03	.430E+02	.450E+04	N.000E+00
CHROMIUM	.140E+04	.200E+03	.700E+00	.960E+02	N.000E+00
COBALT	.740E+02	.240E+03	.800E-01	.630E+00	N.000E+00
COPPER	.650E+03	.180E+03	.000E+00	.296E+00	N.000E+00
DYSPROSIUM	.900E+01	<.500E+00	.000E+00	.000E+00	N.000E+00
ERBIUM	.400E+01	<.200E+00	.000E+00	.000E+00	N.000E+00
EUROPIUM	.300E+01	.300E+00	.000E+00	.000E+00	N.000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.340E+03	.310E+03	.780E+02	.418E+02	N.000E+00
GADOLINIUM	.800E+01	.100E+01	.000E+00	.000E+00	N.000E+00
GALLIUM	.290E+03	>.100E+04	.000E+00	.230E-01	N.000E+00
GERMANIUM	.440E+02	.330E+03	.100E-01	.100E-02	N.000E+00
HAFNIUM	.300E+01	.000E+00	.000E+00	.000E+00	N.000E+00
HOLMIUM	.600E+01	<.300E+00	.000E+00	<.100E+00	N.000E+00
IODINE	.120E+02	.700E+01	.400E-01	.195E+00	N.000E+00
IRON	.112E+06	.394E+05	.500E+01	.449E+03	N.000E+00
LANTHANUM	.900E+02	.300E+01	.000E+00	.000E+00	N.000E+00
LEAD	.890E+03	.469E+05	.000E+00	.000E+00	N.000E+00
LITHIUM	.200E+03	>.310E+03	.000E+00	.360E-01	N.000E+00
LUTETIUM	.100E+01	.000E+00	.000E+00	.000E+00	N.000E+00
MAGNESIUM	.400E+04	.100E+04	.000E+00	.170E+01	N.000E+00
MANGANESE	.200E+03	.400E+03	.000E+00	.199E+01	N.000E+00
MERCURY	.600E+01	.110E+00	.210E+00	.900E-02	.100E-01
MOLYBDENUM	.140E+03	.170E+03	.190E+01	.200E+00	N.000E+00
NEODYMIUM	.480E+02	.400E+01	.000E+00	.000E+00	N.000E+00
NICKEL	.250E+03	.250E+03	.000E+00	.710E+02	N.000E+00
NIOBIUM	.290E+02	.200E+01	.000E+00	.200E-02	N.000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.171E+05	.393E+05	.640E+01	.200E+00	N.000E+00
PLATINUM	.000E+00	.000E+00	.100E+00	.000E+00	N.000E+00

INPUT DATA

ROCK OF AGES
TEST2 - COAL/PET
PPM

ELEMENT	10U + 3U CYCLONES	FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGER
POTASSIUM	.122E+05	.286E+05	.000E+00	.400E+00	N.000E+00
PRASEODYMIUM	.220E+02	.100E+01	.000E+00	.000E+00	N.000E+00
RUBIDIUM	.220E+02	.960E+02	<.100E-01	.600E-02	N.000E+00
SAMARIUM	.200E+02	.200E+01	.000E+00	.000E+00	N.000E+00
SCANDIUM	.500E+02	.130E+02	.000E+00	<.100E-02	N.000E+00
SELENIUM	.680E+03	.300E+03	.460E+00	.294E+00	N.000E+00
SILICON	.150E+06	.389E+05	.190E+02	.116E+02	N.000E+00
SILVER	.120E+02	.190E+02	.000E+00	.200E-01	N.000E+00
SODIUM	.520E+04	.570E+04	.000E+00	.200E+04	N.000E+00
STRONTIUM	.690E+03	.710E+02	.000E+00	.140E-01	N.000E+00
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.306E+05	.258E+05	.170E+02	.770E+04	N.000E+00
TANTALUM	.400E+01	.400E+01	.000E+00	.000E+00	N.000E+00
TELLURIUM	.600E+01	.800E+01	.000E+00	.300E-02	N.000E+00
TERBIUM	.200E+01	.200E+00	.000E+00	.000E+00	N.000E+00
THALLIUM	.420E+02	.960E+02	.000E+00	.000E+00	N.000E+00
THORIUM	.800E+01	.200E+01	.000E+00	.000E+00	N.000E+00
THULIUM	.800E+00	.000E+00	.000E+00	.000E+00	N.000E+00
TIN	.350E+02	.250E+03	.000E+00	.000E+00	N.000E+00
TITANIUM	.830E+04	.110E+03	.700E+00	.370E+00	N.000E+00
TUNGSTEN	.190E+02	.330E+02	.000E+00	.000E+00	N.000E+00
URANIUM	.900E+01	.780E+02	.000E+00	.000E+00	N.000E+00
VANADIUM	.320E+03	.170E+03	.100E-01	.190E-01	N.000E+00
YTTERBIUM	.100E+02	.000E+00	.000E+00	.000E+00	N.000E+00
YTTRIUM	.640E+02	.700E+01	.000E+00	.000E+00	N.000E+00
ZINC	.680E+03	.100E+04	.000E+00	.250E+00	N.000E+00
ZIRCONIUM	.560E+02	.600E+01	<.200E-01	.000E+00	N.000E+00

MASS / FLUE VOLUME

ROCK OF AGES
TEST2 - COAL/PET
MCG/DSCM

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGER
ALUMINUM	.211E+04	.300E+03	.781E+01	.267E+02	N .000E+00
ANTIMONY	.159E+02	< .231E+01	.000E+00	.000E+00	.445E-01
ARSENIC	.189E+02	.300E+02	.104E+00	.374E+00	.000E+00
BARIUM	.194E+02	.122E+01	.521E+00	.000E+00	N .000E+00
BERYLLIUM	.101E+01	.577E+00	.000E+00	.000E+00	N .000E+00
BISMUTH	.468E+00	.198E+01	.000E+00	.000E+00	N .000E+00
BORON	< .187E+01	> .231E+02	.312E+00	.321E+00	N .000E+00
BROMINE	.515E+01	.554E+01	.156E+01	.374E+01	N .000E+00
CADMIUM	.157E+01	.161E+02	.000E+00	.000E+00	N .000E+00
CALCIUM	.320E+03	.577E+02	.000E+00	.107E+03	N .000E+00
CERIUM	.175E+01	.692E-01	.000E+00	.000E+00	N .000E+00
CESIUM	.935E-01	.369E+00	.104E+01	.374E+00	N .000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.982E+02	.692E+01	.224E+03	.241E+06	N .000E+00
CHROMIUM	.327E+02	.461E+01	.364E+01	.513E+04	N .000E+00
COBALT	.173E+01	.554E+01	.416E+00	.337E+02	N .000E+00
COPPER	.152E+02	.415E+01	.000E+00	.158E+02	N .000E+00
DYSPROSIUM	.210E+00	< .115E-01	.000E+00	.000E+00	N .000E+00
ERBIUM	.935E-01	< .461E-02	.000E+00	.000E+00	N .000E+00
EUROPIUM	.702E-01	.692E-02	.000E+00	.000E+00	N .000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.795E+01	.715E+01	.406E+03	.223E+04	N .000E+00
GADOLINIUM	.187E+00	.231E-01	.000E+00	.000E+00	N .000E+00
GALLIUM	.678E+01	> .231E+02	.000E+00	.123E+01	N .000E+00
GERMANIUM	.103E+01	.761E+01	.521E-01	.535E-01	N .000E+00
HAFNIUM	.702E-01	.000E+00	.000E+00	.000E+00	N .000E+00
HOLMIUM	.140E+00	< .692E-02	.000E+00	< .535E+01	N .000E+00
IODINE	.281E+00	.161E+00	.208E+00	.104E+02	N .000E+00
IRON	.262E+04	.909E+03	.260E+02	.240E+05	N .000E+00
LANTHANUM	.210E+01	.692E-01	.000E+00	.000E+00	N .000E+00
LEAD	.208E+02	.108E+04	.000E+00	.000E+00	N .000E+00
LITHIUM	.468E+01	> .715E+01	.000E+00	.192E+01	N .000E+00
LUTETIUM	.234E-01	.000E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	.935E+02	.231E+02	.000E+00	.909E+02	N .000E+00
MANGANESE	.468E+01	.923E+01	.000E+00	.106E+03	N .000E+00
MERCURY	.140E+00	.254E-02	.109E+01	.481E+00	.445E+00
MOLYBDENUM	.327E+01	.392E+01	.989E+01	.107E+02	N .000E+00
NEODYMIUM	.112E+01	.923E-01	.000E+00	.000E+00	N .000E+00
NICKEL	.585E+01	.577E+01	.000E+00	.380E+04	N .000E+00
NIOBIUM	.678E+00	.461E-01	.000E+00	.107E+00	N .000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.400E+03	.907E+03	.333E+02	.107E+02	N .000E+00
PLATINUM	.000E+00	.000E+00	.521E+00	.000E+00	N .000E+00

ROCK OF AGES
MASS / FLUE VOLUME TEST2 - COAL/PET
MCG/DSCM

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGER
POTASSIUM	.285E+03	.660E+03	.000E+00	.214E+02	N .000E+00
PRASEODYMIUM	.515E+00	.231E-01	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.515E+00	.221E+01	< .521E-01	.321E+00	N .000E+00
SAMARIUM	.468E+00	.461E-01	.000E+00	.000E+00	N .000E+00
SCANDIUM	.117E+01	.300E+00	.000E+00	< .535E-01	N .000E+00
SELENIUM	.159E+02	.692E+01	.239E+01	.157E+02	N .000E+00
SILICON	.350E+04	.897E+03	.989E+02	.620E+03	N .000E+00
SILVER	.281E+00	.438E+00	.000E+00	.107E+01	N .000E+00
SODIUM	.122E+03	.131E+03	.000E+00	.107E+06	N .000E+00
STRONTIUM	.161E+02	.164E+01	.000E+00	.748E+00	N .000E+00
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.716E+03	.595E+03	.885E+02	.412E+06	N .000E+00
TANTALUM	.935E-01	.923E-01	.000E+00	.000E+00	N .000E+00
TELLURIUM	.140E+00	.185E+00	.000E+00	.160E+00	N .000E+00
TERBIUM	.468E-01	.461E-02	.000E+00	.000E+00	N .000E+00
THALLIUM	.982E+00	.221E+01	.000E+00	.000E+00	N .000E+00
THORIUM	.187E+00	.461E-01	.000E+00	.000E+00	N .000E+00
THULIUM	.187E-01	.000E+00	.000E+00	.000E+00	N .000E+00
TIN	.819E+00	.577E+01	.000E+00	.000E+00	N .000E+00
TITANIUM	.194E+03	.254E+01	.364E+01	.198E+02	N .000E+00
TUNGSTEN	.444E+00	.761E+00	.000E+00	.000E+00	N .000E+00
URANIUM	.210E+00	.180E+01	.000E+00	.000E+00	N .000E+00
VANADIUM	.748E+01	.392E+01	.521E-01	.102E+01	N .000E+00
YTTERBIUM	.234E+00	.000E+00	.000E+00	.000E+00	N .000E+00
YTTRIUM	.150E+01	.161E+00	.000E+00	.000E+00	N .000E+00
ZINC	.159E+02	.231E+02	.000E+00	.134E+02	N .000E+00
ZIRCONIUM	.131E+01	.138E+00	< .104E+00	.000E+00	N .000E+00

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                                      ROCK OF AGES
MASS / FLUE VOLUME                    TEST2 - COAL/PET
                                      MCG/DSCM
ELEMENT         STACK EXHAUST

ALUMINUM                .245E+04
ANTIMONY       .159E+02<X<.183E+02
ARSENIC                 .494E+02
BARIUM                  .212E+02
BERYLLIUM               .158E+01

BISMUTH                 .245E+01
BORON                 > .237E+02
BROMINE                 .160E+02
CADMIUM                 .177E+02
CALCIUM                 .485E+03

CERIUM                  .182E+01
CESIUM                  .188E+01
CHLORIDE                .000E+00
CHLORINE                .241E+06
CHROMIUM                .517E+04

COBALT                  .414E+02
COPPER                  .352E+02
DYSPROSIUM     .210E+00<X<.222E+00
ERBIUM         .935E-01<X<.982E-01
EUROPIUM                .771E-01

FLUORIDE                .000E+00
FLUORINE                .266E+04
GADOLINIUM              .210E+00
GALLIUM               > .311E+02
GERMANIUM               .875E+01

HAFNIUM                 .702E-01
HOLMIUM        .140E+00<X<.549E+01
IODINE                  .111E+02
IRON                    .276E+05
LANTHANUM               .217E+01

LEAD                    .110E+04
LITHIUM               > .138E+02
LUTETIUM                .234E-01
MAGNESIUM               .208E+03
MANGANESE               .120E+03

MERCURY                 .216E+01
MOLYBDENUM              .278E+02
NEODYMIUM               .121E+01
NICKEL                  .381E+04
NIOBIUM                 .831E+00

NITRATE                 .000E+00
NITRITE                 .000E+00
PHOSPHATE               .000E+00
PHOSPHORUS              .135E+04
PLATINUM                .521E+00
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                                        ROCK OF AGES
MASS / FLUE VOLUME                      TEST2 - COAL/PET
                                        MCG/DSCM
ELEMENT         STACK EXHAUST

POTASSIUM                .966E+03
PRASEODYMIUM             .538E+00
RUBIDIUM         .305E+01<X<.310E+01
SAMARIUM                 .514E+00
SCANDIUM         .147E+01<X<.152E+01

SELENIUM                 .409E+02
SILICON                  .512E+04
SILVER                   .179E+01
SODIUM                   .107E+06
STRONTIUM                .185E+02

SULFATE                  .000E+00
SULFITE                  .000E+00
SULFUR                   .413E+06
TANTALUM                 .186E+00
TELLURIUM                .485E+00

TERBIUM                  .514E-01
THALLIUM                 .320E+01
THORIUM                  .233E+00
THULIUM                  .187E-01
TIN                      .659E+01

TITANIUM                 .220E+03
TUNGSTEN                 .121E+01
URANIUM                  .201E+01
VANADIUM                 .125E+02
YTTERBIUM                .234E+00

YTTRIUM                  .166E+01
ZINC                     .523E+02
ZIRCONIUM        .145E+01<X<.155E+01
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ROCK OF AGES
TEST2 - COAL/PET
NG/J

MASS / HEAT INPUT

ELEMENT	FUEL - COAL/PET	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
ALUMINUM	.503E+03	.348E+03	.474E+01	.143E+01
ANTIMONY	.773E+00	.317E-01	.185E-02	.935E-02<X<.107E-01
ARSENIC	.966E-01	.148E-01	.499E-02	.290E-01
BARIUM	.132E+01	.208E+01	.256E-01	.124E-01
BERYLLIUM	.258E-01	.508E-01	.712E-03	.927E-03
BISMUTH	.644E-01	.000E+00	.712E-04	.144E-02
BORON	.451E+00	.275E+00	.598E-01	> .139E-01
BROMINE	.322E+00	.106E-01	.548E-02	.937E-02
CADMIUM	.644E-01	.846E-02	.570E-03	.104E-01
CALCIUM	.300E+02	.548E+02	.162E+01	.284E+00
CERIUM	.129E+00	.888E-01	.157E-02	.107E-02
CESIUM	.290E-01	.106E-01	.142E-03	.110E-02
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.741E+02	.761E-01	.178E-01	.141E+03
CHROMIUM	.139E+01	.465E+00	.484E-02	.303E+01
COBALT	.290E+00	.233E+00	.712E-03	.242E-01
COPPER	.870E+00	.102E+00	.321E-02	.206E-01
DYSPROSIUM	.000E+00	.169E-01	.356E-03	.123E-03<X<.130E-03
ERBIUM	.000E+00	.846E-02	.142E-03	.548E-04<X<.575E-04
EUROPIUM	.000E+00	.846E-02	.570E-04	.452E-04
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.229E+01	.529E+00	.271E-01	.156E+01
GADOLINIUM	.000E+00	.169E-01	.142E-03	.123E-03
GALLIUM	.161E+00	.133E+00	.157E-02	> .182E-01
GERMANIUM	< .322E-02	.846E-02	.570E-03	.513E-02
HAFNIUM	.000E+00	.106E-01	< .499E-04	.411E-04
HOLMIUM	.000E+00	.106E-01	.214E-03	.822E-04<X<.322E-02
IODINE	.290E-01	.148E-02	.570E-03	.649E-02
IRON	.122E+03	.816E+02	.803E+01	.162E+02
LANTHANUM	.193E+00	.140E+00	.249E-02	.127E-02
LEAD	.902E+00	.110E+00	.499E-02	.646E+00
LITHIUM	.161E+00	.114E+00	.271E-01	> .806E-02
LUTETIUM	.000E+00	.190E-02	.142E-04	.137E-04
MAGNESIUM	.119E+02	.994E+01	.306E+00	.122E+00
MANGANESE	.548E+00	.152E+00	.192E-02	.705E-01
MERCURY	.644E-02	< .212E-04	.819E-04	.127E-02
MOLYBDENUM	.548E+00	.338E-01	.142E-02	.163E-01
NEODYMIUM	.129E+00	.677E-01	.107E-02	.712E-03
NICKEL	.110E+02	.317E+00	.278E-02	.223E+01
NIOBIUM	.644E-01	.317E-01	.641E-03	.487E-03
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.548E+01	.212E+01	.235E+00	.792E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.305E-03

MASS / HEAT INPUT

ROCK OF AGES
TEST2 - COAL/PET
NG/J

ELEMENT	FUEL - COAL/PET	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
POTASSIUM	.293E+02	.241E+02	.456E+00	.566E+00
PRASEODYMIUM	.644E-01	.212E-01	.499E-03	.315E-03
RUBIDIUM	.644E-01	.529E-01	.356E-03	.179E-02<X<.182E-02
SAMARIUM	.322E-01	.317E-01	.285E-03	.301E-03
SCANDIUM	.290E+00	.867E-01	.570E-03	.861E-03<X<.892E-03
SELENIUM	.129E+00	.360E-01	.926E-02	.240E-01
SILICON	.441E+03	.450E+03	.701E+01	.300E+01
SILVER	.000E+00	.127E-02	.712E-04	.105E-02
SODIUM	.119E+02	.110E+02	.192E+00	.628E+02
STRONTIUM	.773E+00	.108E+01	.121E-01	.109E-01
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.213E+03	.114E+02	.200E+01	.242E+03
TANTALUM	.966E-01	.106E-01	.712E-04	.109E-03
TELLURIUM	.000E+00	.635E-03	.285E-04	.284E-03
TERBIUM	.000E+00	.635E-02	.427E-04	.301E-04
THALLIUM	.000E+00	.846E-02	.997E-03	.187E-02
THORIUM	.129E+00	.656E-01	.784E-03	.137E-03
THULIUM	.000E+00	.212E-02	.285E-04	.110E-04
TIN	.290E-01	.423E-02	.356E-03	.386E-02
TITANIUM	.155E+02	.157E+02	.321E+00	.129E+00
TUNGSTEN	.000E+00	.846E-02	.142E-03	.707E-03
URANIUM	.644E-01	.465E-01	.855E-03	.118E-02
VANADIUM	.354E+00	.508E-01	.321E-02	.731E-02
YTTERBIUM	.000E+00	.148E-01	.712E-04	.137E-03
YTTRIUM	.129E+00	.131E+00	.784E-03	.972E-03
ZINC	.322E+00	.486E-01	.627E-02	.307E-01
ZIRCONIUM	.258E+00	.195E+00	.135E-02	.849E-03<X<.910E-03

MASS / HEAT INPUT

ROCK OF AGES
TEST2 - COAL/PET
NG/J

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGER
ALUMINUM	.124E+01	.176E+00	.458E-02	.157E-01	N .000E+00
ANTIMONY	.932E-02	< .135E-02	.000E+00	.000E+00	.261E-04
ARSENIC	.111E-01	.176E-01	.610E-04	.219E-03	.000E+00
BARIUM	.114E-01	.717E-03	.305E-03	.000E+00	N .000E+00
BERYLLIUM	.589E-03	.338E-03	.000E+00	.000E+00	N .000E+00
BISMUTH	.274E-03	.116E-02	.000E+00	.000E+00	N .000E+00
BORON	< .110E-02	> .135E-01	.183E-03	.188E-03	N .000E+00
BROMINE	.302E-02	.324E-02	.915E-03	.219E-02	N .000E+00
CADMIUM	.918E-03	.946E-02	.000E+00	.000E+00	N .000E+00
CALCIUM	.188E+00	.338E-01	.000E+00	.627E-01	N .000E+00
CERIUM	.103E-02	.406E-04	.000E+00	.000E+00	N .000E+00
CESIUM	.548E-04	.216E-03	.610E-03	.219E-03	N .000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.576E-01	.406E-02	.131E+00	.141E+03	N .000E+00
CHROMIUM	.192E-01	.270E-02	.214E-02	.301E+01	N .000E+00
COBALT	.101E-02	.324E-02	.244E-03	.197E-01	N .000E+00
COPPER	.891E-02	.243E-02	.000E+00	.928E-02	N .000E+00
DYSPROSIUM	.123E-03	< .676E-05	.000E+00	.000E+00	N .000E+00
ERBIUM	.548E-04	< .270E-05	.000E+00	.000E+00	N .000E+00
EUROPIUM	.411E-04	.406E-05	.000E+00	.000E+00	N .000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.466E-02	.419E-02	.238E+00	.131E+01	N .000E+00
GADOLINIUM	.110E-03	.135E-04	.000E+00	.000E+00	N .000E+00
GALLIUM	.398E-02	> .135E-01	.000E+00	.721E-03	N .000E+00
GERMANIUM	.603E-03	.446E-02	.305E-04	.313E-04	N .000E+00
HAFNIUM	.411E-04	.000E+00	.000E+00	.000E+00	N .000E+00
HOLMIUM	.822E-04	< .406E-05	.000E+00	< .313E-02	N .000E+00
IODINE	.164E-03	.946E-04	.122E-03	.611E-02	N .000E+00
IRON	.154E+01	.533E+00	.153E-01	.141E+02	N .000E+00
LANTHANUM	.123E-02	.406E-04	.000E+00	.000E+00	N .000E+00
LEAD	.122E-01	.634E+00	.000E+00	.000E+00	N .000E+00
LITHIUM	.274E-02	> .419E-02	.000E+00	.113E-02	N .000E+00
LUTETIUM	.137E-04	.000E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	.548E-01	.135E-01	.000E+00	.533E-01	N .000E+00
MANGANESE	.274E-02	.541E-02	.000E+00	.624E-01	N .000E+00
MERCURY	.822E-04	.149E-05	.641E-03	.282E-03	.261E-03
MOLYBDENUM	.192E-02	.230E-02	.580E-02	.627E-02	N .000E+00
NEODYMIUM	.658E-03	.541E-04	.000E+00	.000E+00	N .000E+00
NICKEL	.343E-02	.338E-02	.000E+00	.222E+01	N .000E+00
NIOBIUM	.398E-03	.270E-04	.000E+00	.627E-04	N .000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.234E+00	.531E+00	.195E-01	.627E-02	N .000E+00
PLATINUM	.000E+00	.000E+00	.305E-03	.000E+00	N .000E+00

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                                ROCK OF AGES
MASS / HEAT INPUT               TEST2 - COAL/PET
                                NG/J
ELEMENT        10U + 3U CYCLONES   1U + FILTERS           XAD-2             FIRST IMPINGER   2ND & 3RD IMPINGER

POTASSIUM              .167E+00            .387E+00            .000E+00            .125E-01        N  .000E+00
PRASEODYMIUM           .302E-03            .135E-04            .000E+00            .000E+00        N  .000E+00
RUBIDIUM               .302E-03            .130E-02          < .305E-04            .188E-03        N  .000E+00
SAMARIUM               .274E-03            .270E-04            .000E+00            .000E+00        N  .000E+00
SCANDIUM               .685E-03            .176E-03            .000E+00          < .313E-04        N  .000E+00

SELENIUM               .932E-02            .406E-02            .140E-02            .921E-02        N  .000E+00
SILICON                .205E+01            .526E+00            .580E-01            .363E+00        N  .000E+00
SILVER                 .164E-03            .257E-03            .000E+00            .627E-03        N  .000E+00
SODIUM                 .713E-01            .771E-01            .000E+00            .626E+02        N  .000E+00
STRONTIUM              .946E-02            .960E-03            .000E+00            .439E-03        N  .000E+00

SULFATE                .000E+00            .000E+00            .000E+00            .000E+00           .000E+00
SULFITE                .000E+00            .000E+00            .000E+00            .000E+00           .000E+00
SULFUR                 .419E+00            .349E+00            .519E-01            .241E+03        N  .000E+00
TANTALUM               .548E-04            .541E-04            .000E+00            .000E+00        N  .000E+00
TELLURIUM              .822E-04            .108E-03            .000E+00            .940E-04        N  .000E+00

TERBIUM                .274E-04            .270E-05            .000E+00            .000E+00        N  .000E+00
THALLIUM               .576E-03            .130E-02            .000E+00            .000E+00        N  .000E+00
THORIUM                .110E-03            .270E-04            .000E+00            .000E+00        N  .000E+00
THULIUM                .110E-04            .000E+00            .000E+00            .000E+00        N  .000E+00
TIN                    .480E-03            .338E-02            .000E+00            .000E+00        N  .000E+00

TITANIUM               .114E+00            .149E-02            .214E-02            .116E-01        N  .000E+00
TUNGSTEN               .260E-03            .446E-03            .000E+00            .000E+00        N  .000E+00
URANIUM                .123E-03            .105E-02            .000E+00            .000E+00        N  .000E+00
VANADIUM               .439E-02            .230E-02            .305E-04            .595E-03        N  .000E+00
YTTERBIUM              .137E-03            .000E+00            .000E+00            .000E+00        N  .000E+00

YTTRIUM                .877E-03            .946E-04            .000E+00            .000E+00        N  .000E+00
ZINC                   .932E-02            .135E-01            .000E+00            .783E-02        N  .000E+00
ZIRCONIUM              .768E-03            .811E-04          < .610E-04            .000E+00        N  .000E+00
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ROCK OF AGES
TEST2 - COAL/PET
MCG/SEC

MASS / TIME

ELEMENT	FUEL - COAL/PET	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
ALUMINUM	.562E+06	.398E+06	.543E+04	.164E+04
ANTIMONY	.864E+03	.363E+02	.212E+01	.107E+02<X<.122E+02
ARSENIC	.108E+03	.169E+02	.570E+01	.331E+02
BARIUM	.148E+04	.238E+04	.293E+02	.142E+02
BERYLLIUM	.288E+02	.581E+02	.815E+00	.106E+01
BISMUTH	.720E+02	.000E+00	.815E-01	.164E+01
BORON	.504E+03	.315E+03	.685E+02	> .159E+02
BROMINE	.360E+03	.121E+02	.628E+01	.107E+02
CADMIUM	.720E+02	.968E+01	.652E+00	.119E+02
CALCIUM	.335E+05	.627E+05	.185E+04	.325E+03
CERIUM	.144E+03	.102E+03	.179E+01	.122E+01
CESIUM	.324E+02	.121E+02	.163E+00	.126E+01
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.828E+05	.871E+02	.204E+02	.162E+06
CHROMIUM	.155E+04	.532E+03	.554E+01	.347E+04
COBALT	.324E+03	.266E+03	.815E+00	.277E+02
COPPER	.972E+03	.116E+03	.367E+01	.236E+02
DYSPROSIUM	.000E+00	.194E+02	.407E+00	.141E+00<X<.149E+00
ERBIUM	.000E+00	.968E+01	.163E+00	.627E-01<X<.658E-01
EUROPIUM	.000E+00	.968E+01	.652E-01	.517E-01
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.256E+04	.605E+03	.310E+02	.178E+04
GADOLINIUM	.000E+00	.194E+02	.163E+00	.141E+00
GALLIUM	.180E+03	.152E+03	.179E+01	> .208E+02
GERMANIUM	< .360E+01	.968E+01	.652E+00	.587E+01
HAFNIUM	.000E+00	.121E+02	< .571E-01	.471E-01
HOLMIUM	.000E+00	.121E+02	.245E+00	.941E-01<X<.368E+01
IODINE	.324E+02	.169E+01	.652E+00	.743E+01
IRON	.137E+06	.934E+05	.919E+04	.185E+05
LANTHANUM	.216E+03	.160E+03	.285E+01	.146E+01
LEAD	.101E+04	.126E+03	.570E+01	.739E+03
LITHIUM	.180E+03	.131E+03	.310E+02	> .922E+01
LUTETIUM	.000E+00	.218E+01	.163E-01	.157E-01
MAGNESIUM	.133E+05	.114E+05	.350E+03	.139E+03
MANGANESE	.612E+03	.174E+03	.220E+01	.807E+02
MERCURY	.720E+01	< .242E-01	.937E-01	.145E+01
MOLYBDENUM	.612E+03	.387E+02	.163E+01	.186E+02
NEODYMIUM	.144E+03	.774E+02	.122E+01	.815E+00
NICKEL	.122E+05	.363E+03	.318E+01	.255E+04
NIOBIUM	.720E+02	.363E+02	.734E+00	.557E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.612E+04	.242E+04	.269E+03	.906E+03
PLATINUM	.000E+00	.000E+00	.000E+00	.349E+00

ROCK OF AGES
TEST2 - COAL/PET
MCG/SEC

MASS / TIME

ELEMENT	FUEL - COAL/PET	BOTTOM ASH	CYCLONE ASH	STACK EXHAUST
POTASSIUM	.328E+05	.276E+05	.522E+03	.648E+03
PRASEODYMIUM	.720E+02	.242E+02	.571E+00	.361E+00
RUBIDIUM	.720E+02	.605E+02	.407E+00	.205E+01<X<.208E+01
SAMARIUM	.360E+02	.363E+02	.326E+00	.345E+00
SCANDIUM	.324E+03	.992E+02	.652E+00	.985E+00<X<.102E+01
SELENIUM	.144E+03	.411E+02	.106E+02	.275E+02
SILICON	.493E+06	.515E+06	.802E+04	.343E+04
SILVER	.000E+00	.145E+01	.815E-01	.120E+01
SODIUM	.133E+05	.126E+05	.220E+03	.718E+05
STRONTIUM	.864E+03	.123E+04	.139E+02	.124E+02
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.238E+06	.131E+05	.229E+04	.277E+06
TANTALUM	.108E+03	.121E+02	.815E-01	.125E+00
TELLURIUM	.000E+00	.726E+00	.326E-01	.325E+00
TERBIUM	.000E+00	.726E+01	.489E-01	.345E-01
THALLIUM	.000E+00	.968E+01	.114E+01	.214E+01
THORIUM	.144E+03	.750E+02	.896E+00	.156E+00
THULIUM	.000E+00	.242E+01	.326E-01	.125E-01
TIN	.324E+02	.484E+01	.407E+00	.442E+01
TITANIUM	.173E+05	.179E+05	.367E+03	.148E+03
TUNGSTEN	.000E+00	.968E+01	.163E+00	.808E+00
URANIUM	.720E+02	.532E+02	.978E+00	.135E+01
VANADIUM	.396E+03	.581E+02	.367E+01	.836E+01
YTTERBIUM	.000E+00	.169E+02	.815E-01	.157E+00
YTTRIUM	.144E+03	.150E+03	.896E+00	.111E+01
ZINC	.360E+03	.557E+02	.717E+01	.351E+02
ZIRCONIUM	.288E+03	.223E+03	.155E+01	.971E+00<X<.104E+01

ROCK OF AGES
TEST2 - COAL/PET
MCG/SEC

MASS / TIME

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGER
ALUMINUM	.142E+04	.201E+03	.524E+01	.179E+02	N .000E+00
ANTIMONY	.107E+02	< .155E+01	.000E+00	.000E+00	.298E-01
ARSENIC	.127E+02	.201E+02	.698E-01	.251E+00	.000E+00
BARIUM	.130E+02	.820E+00	.349E+00	.000E+00	N .000E+00
BERYLLIUM	.674E+00	.387E+00	.000E+00	.000E+00	N .000E+00
BISMUTH	.314E+00	.133E+01	.000E+00	.000E+00	N .000E+00
BORON	< .125E+01	> .155E+02	.209E+00	.215E+00	N .000E+00
BROMINE	.345E+01	.371E+01	.105E+01	.251E+01	N .000E+00
CADMIUM	.105E+01	.108E+02	.000E+00	.000E+00	N .000E+00
CALCIUM	.215E+03	.387E+02	.000E+00	.717E+02	N .000E+00
CERIUM	.118E+01	.464E-01	.000E+00	.000E+00	N .000E+00
CESIUM	.627E-01	.248E+00	.698E+00	.251E+00	N .000E+00
CHLORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
CHLORINE	.659E+02	.464E+01	.150E+03	.161E+06	N .000E+00
CHROMIUM	.220E+02	.309E+01	.244E+01	.344E+04	N .000E+00
COBALT	.116E+01	.371E+01	.279E+00	.226E+02	N .000E+00
COPPER	.102E+02	.278E+01	.000E+00	.106E+02	N .000E+00
DYSPROSIUM	.141E+00	< .773E-02	.000E+00	.000E+00	N .000E+00
ERBIUM	.627E-01	< .309E-02	.000E+00	.000E+00	N .000E+00
EUROPIUM	.471E-01	.464E-02	.000E+00	.000E+00	N .000E+00
FLUORIDE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
FLUORINE	.533E+01	.480E+01	.272E+03	.150E+04	N .000E+00
GADOLINIUM	.125E+00	.155E-01	.000E+00	.000E+00	N .000E+00
GALLIUM	.455E+01	> .155E+02	.000E+00	.825E+00	N .000E+00
GERMANIUM	.690E+00	.510E+01	.349E-01	.359E-01	N .000E+00
HAFNIUM	.471E-01	.000E+00	.000E+00	.000E+00	N .000E+00
HOLMIUM	.941E-01	< .464E-02	.000E+00	< .359E+01	N .000E+00
IODINE	.188E+00	.108E+00	.140E+00	.699E+01	N .000E+00
IRON	.176E+04	.609E+03	.175E+02	.161E+05	N .000E+00
LANTHANUM	.141E+01	.464E-01	.000E+00	.000E+00	N .000E+00
LEAD	.140E+02	.725E+03	.000E+00	.000E+00	N .000E+00
LITHIUM	.314E+01	> .480E+01	.000E+00	.129E+01	N .000E+00
LUTETIUM	.157E-01	.000E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	.627E+02	.155E+02	.000E+00	.609E+02	N .000E+00
MANGANESE	.314E+01	.619E+01	.000E+00	.713E+02	N .000E+00
MERCURY	.941E-01	.170E-02	.733E+00	.323E+00	.298E+00
MOLYBDENUM	.220E+01	.263E+01	.663E+01	.717E+01	N .000E+00
NEODYMIUM	.753E+00	.619E-01	.000E+00	.000E+00	N .000E+00
NICKEL	.392E+01	.387E+01	.000E+00	.255E+04	N .000E+00
NIOBIUM	.455E+00	.309E-01	.000E+00	.717E-01	N .000E+00
NITRATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
NITRITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
PHOSPHORUS	.268E+03	.608E+03	.223E+02	.717E+01	N .000E+00
PLATINUM	.000E+00	.000E+00	.349E+00	.000E+00	N .000E+00

ROCK OF AGES
TEST2 - COAL/PET
MCG/SEC

MASS / TIME

ELEMENT	10U + 3U CYCLONES	1U + FILTERS	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGER
POTASSIUM	.191E+03	.442E+03	.000E+00	.143E+02	N .000E+00
PRASEODYMIUM	.345E+00	.155E-01	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.345E+00	.149E+01	< .349E-01	.215E+00	N .000E+00
SAMARIUM	.314E+00	.309E-01	.000E+00	.000E+00	N .000E+00
SCANDIUM	.784E+00	.201E+00	.000E+00	< .359E-01	N .000E+00
SELENIUM	.107E+02	.464E+01	.161E+01	.105E+02	N .000E+00
SILICON	.235E+04	.602E+03	.663E+02	.416E+03	N .000E+00
SILVER	.188E+00	.294E+00	.000E+00	.717E+00	N .000E+00
SODIUM	.816E+02	.882E+02	.000E+00	.717E+05	N .000E+00
STRONTIUM	.108E+02	.110E+01	.000E+00	.502E+00	N .000E+00
SULFATE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFITE	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
SULFUR	.480E+03	.399E+03	.594E+02	.276E+06	N .000E+00
TANTALUM	.627E-01	.619E-01	.000E+00	.000E+00	N .000E+00
TELLURIUM	.941E-01	.124E+00	.000E+00	.108E+00	N .000E+00
TERBIUM	.314E-01	.309E-02	.000E+00	.000E+00	N .000E+00
THALLIUM	.659E+00	.149E+01	.000E+00	.000E+00	N .000E+00
THORIUM	.125E+00	.309E-01	.000E+00	.000E+00	N .000E+00
THULIUM	.125E-01	.000E+00	.000E+00	.000E+00	N .000E+00
TIN	.549E+00	.387E+01	.000E+00	.000E+00	N .000E+00
TITANIUM	.130E+03	.170E+01	.244E+01	.133E+02	N .000E+00
TUNGSTEN	.298E+00	.510E+00	.000E+00	.000E+00	N .000E+00
URANIUM	.141E+00	.121E+01	.000E+00	.000E+00	N .000E+00
VANADIUM	.502E+01	.263E+01	.349E-01	.681E+00	N .000E+00
YTTERBIUM	.157E+00	.000E+00	.000E+00	.000E+00	N .000E+00
YTTRIUM	.100E+01	.108E+00	.000E+00	.000E+00	N .000E+00
ZINC	.107E+02	.155E+02	.000E+00	.896E+01	N .000E+00
ZIRCONIUM	.878E+00	.928E-01	< .698E-01	.000E+00	N .000E+00

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                         ROCK OF AGES
                         TEST2 - COAL/PET

                         BOILER MASS BALANCE
             INPUT = FUEL; OUTPUT = BOTTOM ASH + CYCLONE ASH + SASS TRAIN            NOTE: ASSUMING 1U-CYCLONE + FILTER HAS FILTER COMP
ELEMENT                      TOTAL IN                     TOTAL OUT                 MASS BALANCE (OUT/IN)

ALUMINUM        .562E+06                     .405E+06                        .721E+00
ANTIMONY        .864E+03                     .491E+02<X<.507E+02             .568E-01<X<.586E-01
ARSENIC         .108E+03                     .558E+02                        .516E+00
BARIUM          .148E+04                     .243E+04                        .164E+01
BERYLLIUM       .288E+02                     .600E+02                        .208E+01

BISMUTH         .720E+02                     .173E+01                        .240E-01
BORON           .504E+03                     .399E+03 <X                     .792E+00 <X
BROMINE         .360E+03                     .291E+02                        .808E-01
CADMIUM         .720E+02                     .222E+02                        .308E+00
CALCIUM         .335E+05                     .649E+05                        .194E+01

CERIUM          .144E+03                     .105E+03                        .727E+00
CESIUM          .324E+02                     .135E+02                        .417E+00
CHLORIDE                                                                            *
CHLORINE        .828E+05                     .162E+06                        .195E+01
CHROMIUM        .155E+04                     .401E+04                        .259E+01

COBALT          .324E+03                     .295E+03                        .910E+00
COPPER          .972E+03                     .143E+03                        .148E+00
DYSPROSIUM                                   .199E+02                               *
ERBIUM                                       .991E+01                               *
EUROPIUM                                     .980E+01                               *

FLUORIDE                                                                            *
FLUORINE        .256E+04                     .242E+04                        .946E+00
GADOLINIUM                                   .197E+02                               *
GALLIUM         .180E+03                     .175E+03 <X                     .973E+00 <X
GERMANIUM                X<.360E+01          .162E+02                        .450E+01 <X

HAFNIUM                                      .122E+02                               *
HOLMIUM                                      .124E+02<X<.160E+02                    *
IODINE          .324E+02                     .977E+01                        .302E+00
IRON            .137E+06                     .121E+06                        .885E+00
LANTHANUM       .216E+03                     .164E+03                        .759E+00

LEAD            .101E+04                     .871E+03                        .864E+00
LITHIUM         .180E+03                     .171E+03 <X                     .949E+00 <X
LUTETIUM                                     .221E+01                               *
MAGNESIUM       .133E+05                     .119E+05                        .891E+00
MANGANESE       .612E+03                     .257E+03                        .420E+00

MERCURY         .720E+01                     .154E+01<X<.157E+01             .214E+00<X<.218E+00
MOLYBDENUM      .612E+03                     .590E+02                        .964E-01
NEODYMIUM       .144E+03                     .795E+02                        .552E+00
NICKEL          .122E+05                     .292E+04                        .238E+00
NIOBIUM         .720E+02                     .376E+02                        .522E+00

NITRATE                                                                             *
NITRITE                                                                             *
PHOSPHATE                                                                           *
PHOSPHORUS      .612E+04                     .359E+04                        .587E+00
PLATINUM                                     .349E+00                               *
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ROCK OF AGES
TEST2 - COAL/PET

BOILER MASS BALANCE
INPUT = FUEL; OUTPUT = BOTTOM ASH + CYCLONE ASH + SASS TRAIN

NOTE: ASSUMING 1U-CYCLONE + FILTER HAS FILTER COMP

ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE (OUT/IN)
POTASSIUM	.328E+05	.288E+05	.878E+00
PRASEODYMIUM	.720E+02	.251E+02	.349E+00
RUBIDIUM	.720E+02	.630E+02	.875E+00
SAMARIUM	.360E+02	.370E+02	.103E+01
SCANDIUM	.324E+03	.101E+03	.311E+00
SELENIUM	.144E+03	.792E+02	.550E+00
SILICON	.493E+06	.526E+06	.107E+01
SILVER		.273E+01	*
SODIUM	.133E+05	.846E+05	.636E+01
STRONTIUM	.864E+03	.126E+04	.146E+01
SULFATE			*
SULFITE			*
SULFUR	.238E+06	.292E+06	.123E+01
TANTALUM	.108E+03	.123E+02	.114E+00
TELLURIUM		.108E+01	*
TERBIUM		.734E+01	*
THALLIUM		.130E+02	*
THORIUM	.144E+03	.761E+02	.528E+00
THULIUM		.247E+01	*
TIN	.324E+02	.966E+01	.298E+00
TITANIUM	.173E+05	.184E+05	.107E+01
TUNGSTEN		.107E+02	*
URANIUM	.720E+02	.556E+02	.772E+00
VANADIUM	.396E+03	.701E+02	.177E+00
YTTERBIUM		.172E+02	*
YTTRIUM	.144E+03	.152E+03	.106E+01
ZINC	.360E+03	.979E+02	.272E+00
ZIRCONIUM	.288E+03	.225E+03	.782E+00